MCDOT
Interim Mechanistic-Empirical (ME) Flexible Pavement Design Guide

Edition 2019-1

Pavement ME Design Version 2.5.5

Adopted: October 31, 2019

Maricopa County
Department of Transportation

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DATE: October 31, 2019

TO: Engineers, Contractors, Consultants and Agency Staff

FROM: Jennifer Toth, P.E.
County Engineer
Transportation Director

SUBJECT: Maricopa County Department of Transportation
Interim Mechanistic-Empirical (ME) Pavement Design Guide
(October 2019)

Effective October 31, 2019, MCDOT pavement designs should be performed using both the MCDOT Roadway Design Manual and this Interim ME Pavement Design Guide. Final pavement structure should be selected based on the outcome of the two methods coupled with engineering judgement.

Comments and suggestions concerning this pavement design guide are welcome. Please address specific issues, concerns, comments, and suggestions to the MCDOT Engineering Division:

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This document is also available on the MCDOT website at:
http://www.mcdot.maricopa.gov/technical/

Enclosure

A.1 Implementation of Pavement ME Design in Maricopa County

The issue of this interim pavement design guide in October 2019 will mark the start of the use of Mechanistic-Empirical (ME) Pavement Design at Maricopa County Department of Transportation (MCDOT). The associated software program is tilted Pavement ME Design. Note that this pavement design guide focuses only on flexible pavement design, rigid pavement design is not covered.

Designers are required to use both this interim guide and Chapter 10 of *MCDOT Roadway Design Manual*[1] (RDM) when providing pavement designs for MCDOT arterial roads that include at least one-half a roadway for a nominal one-half mile length or greater. The designer should use designs from both methods and engineering judgement in selecting the suitable pavement structure.

The efforts toward the implementation of Pavement ME Design at Maricopa County began in 2006 with a research program funded by MCDOT. The pavement and geotechnical groups at Arizona State University (ASU) provided the required material characterization services between 2006 and 2009 under this research program. Fifteen roadway projects, which included nine new flexible pavement constructions, four intersection improvements, and two overlay projects, were selected as test sections to perform sampling, material characterization, field monitoring, calibration and validation. The sampling, field monitoring, calibration, and validation were conducted by MCDOT's materials group.

In 2016, calibration and validation of the Pavement ME Design was performed using the latest available AASHTO Pavement ME Design software at the time (Version 2.3.0, Revision 65), after gathering field distress measurements of the test sections over a ten year period. The calibration and validation process included checking the National and Arizona Department of Transportation (ADOT) calibration factors for Maricopa County conditions and identifying any bias in predicted distresses. Then, the identified bias was eliminated or reduced by adjusting selected critical calibration factors. The applicable procedures and guidance given in the *AASHTO Guide for the Local Calibration of the Mechanistic-Empirical Pavement Design Guide*, *November 2010*[2] was followed during the calibration and validation process. The findings were presented in a conference paper titled *Implementation Process of Pavement ME Design in Maricopa County*[3] at the 13th Arizona Pavement/Materials Conference held in November 2016. MCDOT is continuing the collection of distress data from the subject roads to verify and improve the distress predictions. Based on the on-going data, the local and national calibration factors will be refined and reported in this document if and when deemed appropriate.

The current pavement design method in use for MCDOT pavement design is the 1993 AASHTO Design Guide. One of the main differences between the 1993 AASHTO Design Guide and the Pavement ME Design can be stated as: the 1993 guide designs the thickness of each pavement layer while the Pavement ME Design predicts the performance of the pavement corresponding to user input layer thicknesses. **Figure 1** illustrates a comparison of the two methods. Detailed comparisons of the two programs are listed in **Table 1**.

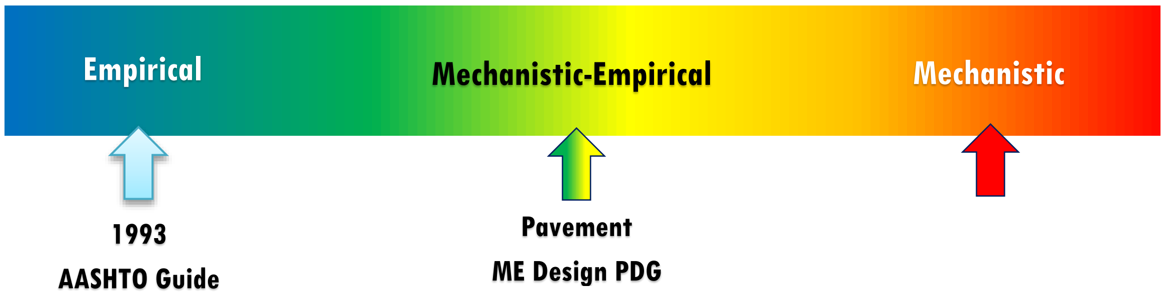


Figure 1. Comparison of 1993 AASHTO Design and Pavement ME Design

This document provides guidance to designers for pavement designs of MCDOT roadways using Pavement ME Design software.

A.2 AASHTO Pavement ME Design Software

The AASHTOWare Pavement ME Design program was first issued in the early 2010s. Development of the flexible pavement design for the ME program was originally developed by Arizona State University (ASU) under a subcontract with Applied Research Associates, Inc. (ARA). At the time of this document, Version 2.5.5 is available for purchase on the AASHTOWare website.

Individual Workstation or Site licenses can be purchased from AASHTOWare on annual basis with annual subscription fees. When performing pavement design for MCDOT roadways, the designers can use their own Pavement ME Design program or contact MCDOT for help or to access the Pavement ME Design program at MCDOT (for MCDOT designers only).

A.3 Data Input

The main data input areas in Pavement ME Design program include climate, traffic, and materials as illustrated in **Figure 2**. The program accepts data in three hierarchical levels designated Level 1, Level 2, and Level 3. Level 1 represents the most advanced level where the designer can input site specific data from material characterization such as dynamic modulus and resilient modulus of the asphalt mix. On the other hand, Level 3 represents the lowest level where the designer can use readily available data such as sieve analysis and plasticity index along with the default data provided by the program. Level 2 can be used when some intermediate test data are available. For example, instead of inputting direct resilient modulus test data for unbound layers (aggregate base and subgrade), R-value or CBR or other parameters can be input so that the program can internally generate a correlated resilient modulus value.

Table 1: Comparison between 1993 AASHTO Guide and Pavement ME Design			
Item No.	**Item**	**1993 Guide**	**Pavement ME Design**
1	Main design output	· Pavement layer thicknesses based on minimum thickness to achieve design life	· Pavement performance over the design life for a given pavement structure
2	Main design inputs	· Traffic AADT and truck content · Resilient modulus of subgrade · Layer coefficients	· Pavement performance based on predictions of the development of key pavement distresses including: Rutting, Fatigue, Thermal Cracking, Bottom-Up Cracking, and Top-Down Cracking. · Based on the hierarchical level (Level 1, 2, & 3) · Thickness of each pavement layer · Traffic (see Item 3): AADTT, Traffic spectra including Class distribution, axle distribution, operational speed · Materials: see Items 4, 5, and 6 · Climate: historical climate data from an extensive weather database provided with the program
3	Traffic load over the lifetime of road	· AADT Converted to ESALs	· No design life ESAL computations · Program estimates the loads that are applied to the pavement and the frequency with which those given loads are applied throughout the pavement's design life
4	Bound layer data input	· Layer coefficients · Elastic modulus of layers	· Dynamic modulus · Binder viscosity · Mixture volumetrics · Creep compliance · Thermal properties · Indirect tensile strength
5	Unbound layer data input	· Layer coefficients · Elastic modulus of layers	· Resilient modulus · Sieve and PI data · Soil-water characteristics · Hydraulic conductivity
6	Subgrade soil data input	· Resilient modulus	· Resilient modulus · Sieve and PI data · Soil-water characteristics · Hydraulic conductivity
7	Design steps	· Convert traffic to design ESALs · Compute the required Structural Number (SN) mainly based on ESALS and subgrade resilient modulus · Determine the layer thicknesses that satisfy the required SN	· Trial pavement structure is subject to expected traffic axle loads over the design period · Pavement material properties are varied over the seasons based on local climatic data · The response of pavement and resulting damage is estimated mechanistically as the virtual time passes through the years · The estimated damage is empirically correlated to various distress types · Performance of the pavement with respect to each category of distress is plotted · Repeat the analysis by revising layer thicknesses until the distresses are within criteria.

Figure 2. Main Data Input Areas in Pavement ME Design

The initial steps of how to start a new project is briefly explained here, then, detailed guide to data entry is given in the following sections. The opening screen of Pavement ME Design is shown in **Figure 3**. Once the **OK** is clicked, the initial screen (**Figure 4**) will appear. A new project can be started by clicking **New** on the top menu bar (**Figure 4**) and the screen in **Figure 5** will appear. An existing ptoject can be opened by clicking **Open**, and selecting the project.

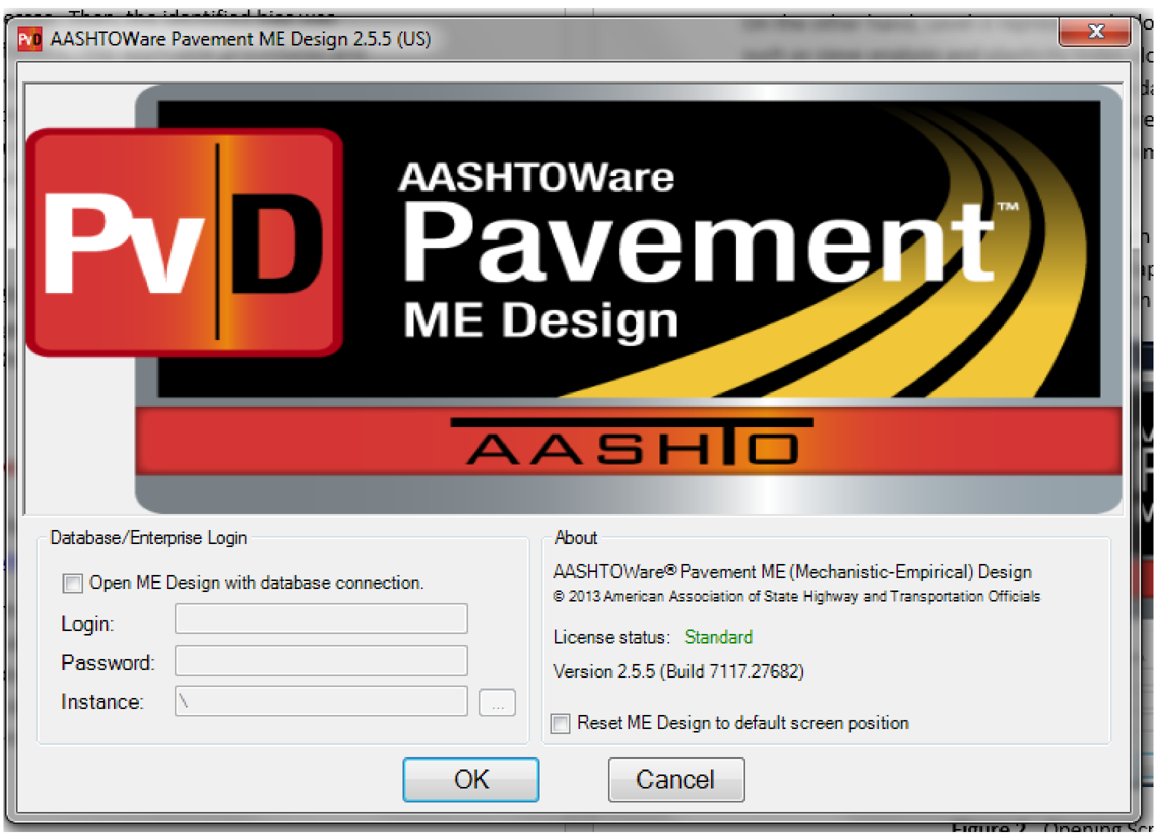


Figure 3. Opening Screen of Pavement ME Design Software

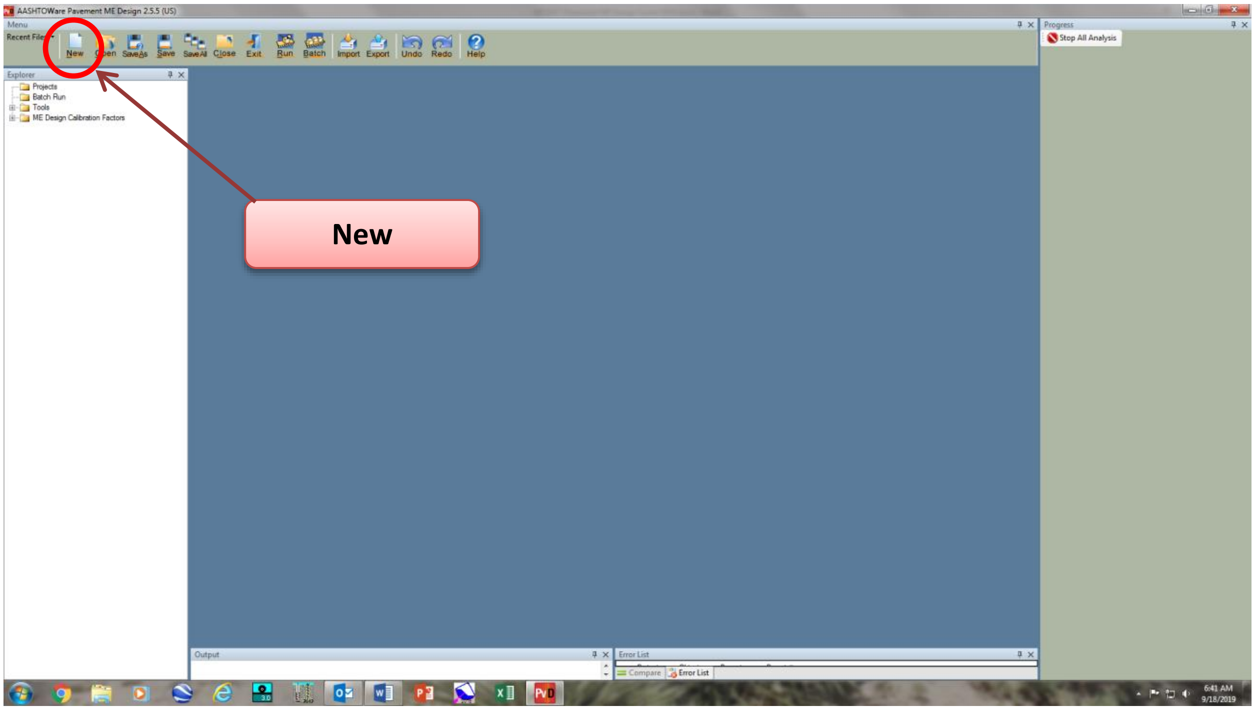


Figure 4. Initial Screen of Pavement ME Design Program

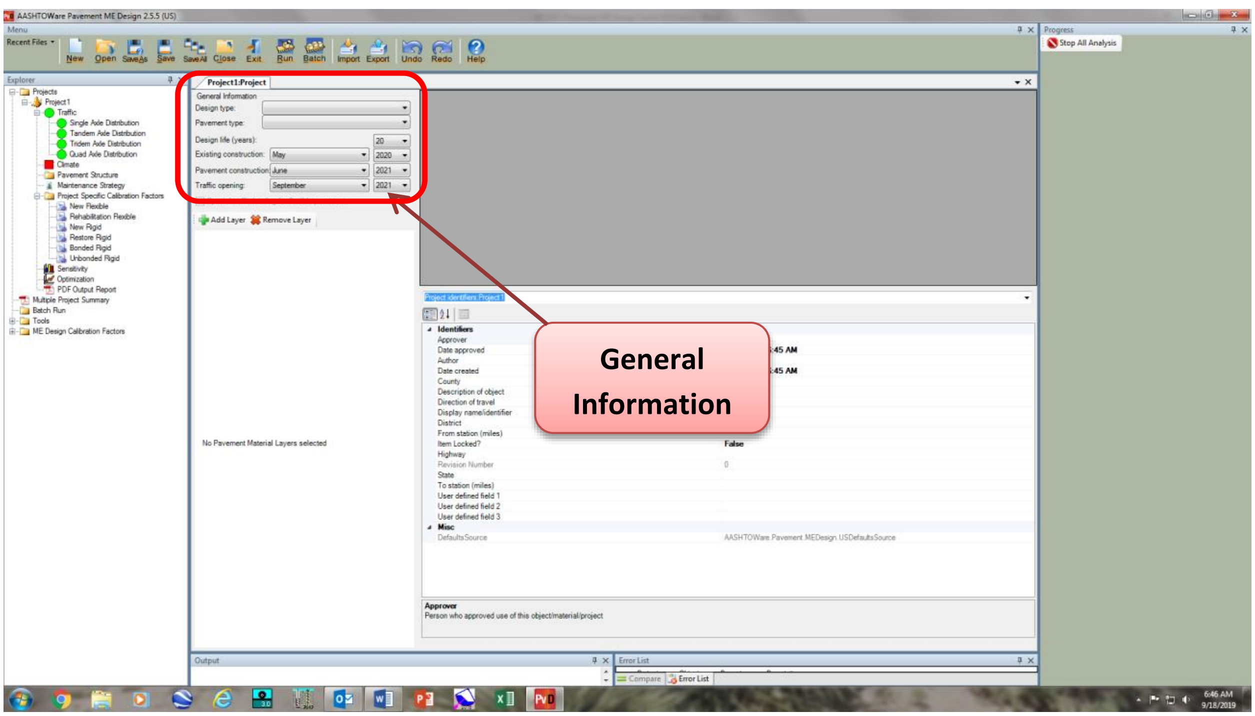


Figure 5. Initial Data Input Screen of Pavement ME Design Program for a New Project

Adding different pavement structure layers is the first step when starting a new pavement design using Pavement ME Design. Decide the type of pavement structure to be analyzed for the given project and follow the steps given below:

1. Open Pavement ME Design program and click **OK** to proceed (**Figure 3**)
2. Click on **New**, and a screen with no structural layers will appear (**Figure 4**)
3. Under **General Information** (**Figure 5**), select **Design Type** as **New Pavement** and select **Pavement Type** as **Flexible Pavement**.
4. Input **Design Life**, typically 20 years.
5. Input the anticipated dates of **Base Construction**, **Pavement Construction**, and **Traffic Opening**.
6. The screen shown in **Figure 6** will appear, and click on **Add Layer** tab with a green icon ( ).
7. **Material Layer Selection** window will appear (**Figure 7**)

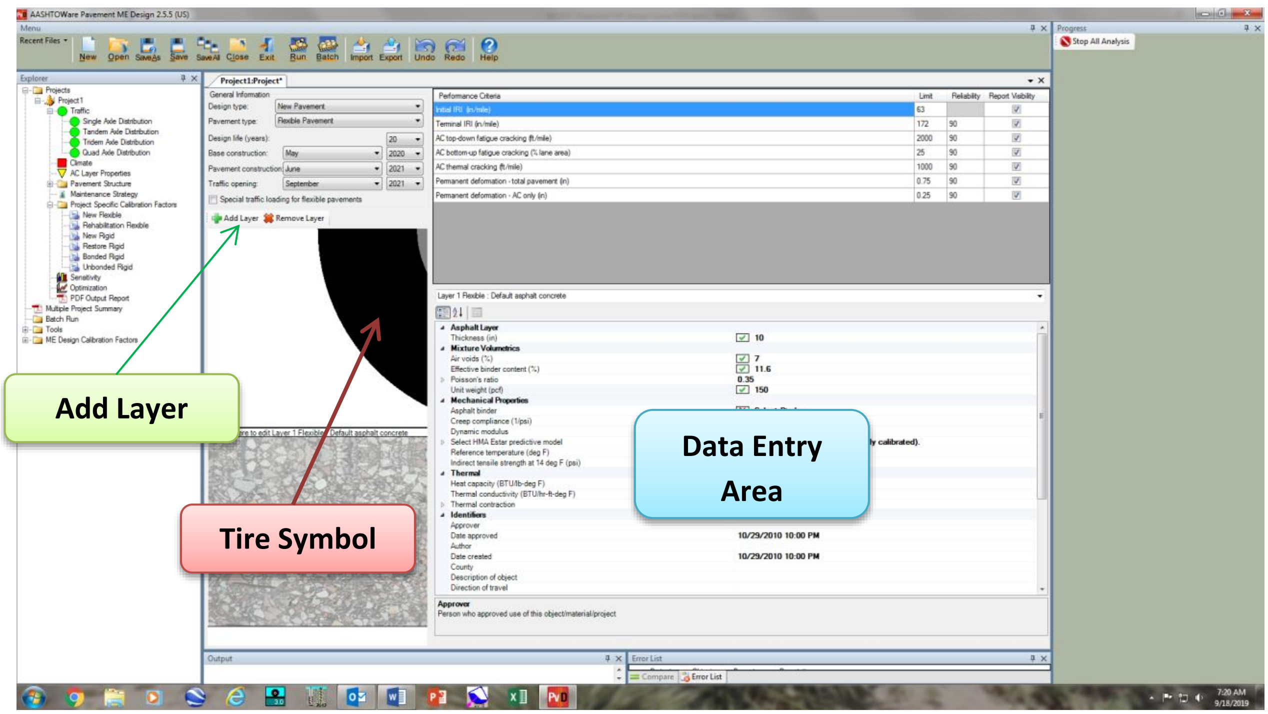


Figure 6. Adding Layers to Pavement ME Design Program for a New Project

8. Select **Layer 1 Flexible: Default asphalt concrete** and select layer type as **Flexible (1)**, using the drop down menu. Note that the built-in layer types in the program include: PCC, Flexible, Sandwiched Granular, Non-Stabilized Base, Subgrade and Bedrock.
9. Select **Default Asphalt Concrete** on the left inset window and click **OK**.
10. A new layer with matching graphics will appear on the screen below the Tire symbol with the respective data entry area showing to the right (**Figure 6**).
11. Repeat steps 8-10 for each pavement structure layer.
12. The respective data entry windows for each layer can be accessed by clicking the layer graphics on the screen.
13. When clicked, the layer becomes slightly shaded indicating the layer is selected.
14. Once all the layers are added, the screen will appear as shown in **Figure 8**.

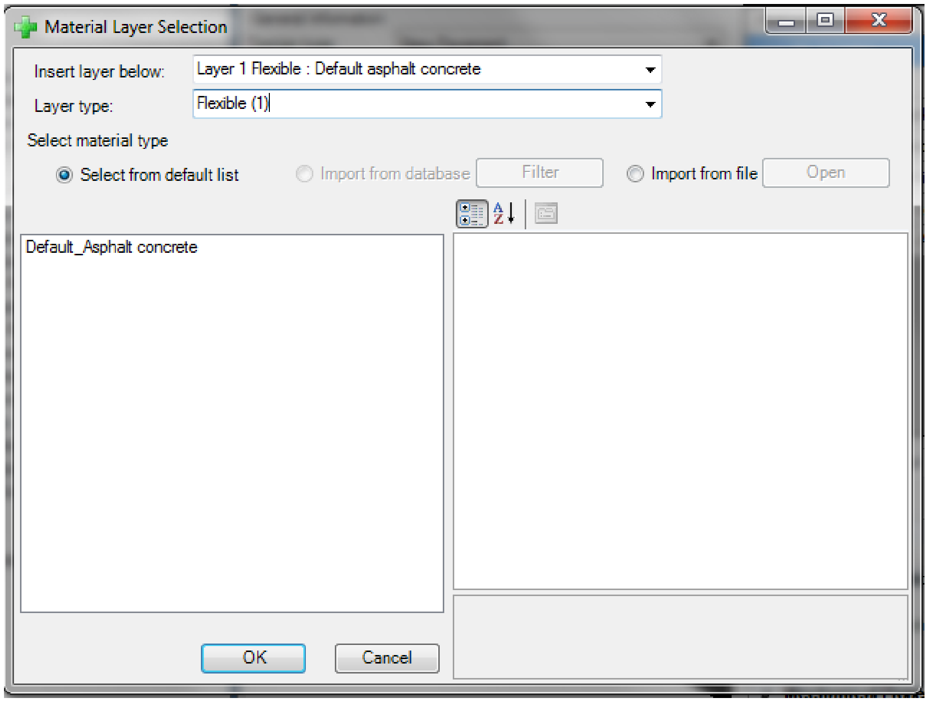


Figure 7. Material Layer Selection Screen of Pavement ME Design Program

Once the layers are added, the data input screen will appear (**Figure 8**). Data input or display areas on this screen are labeled as **A** through **I** for reference purposes and is described in **Table 2**. Some information may be repeated for clarity.

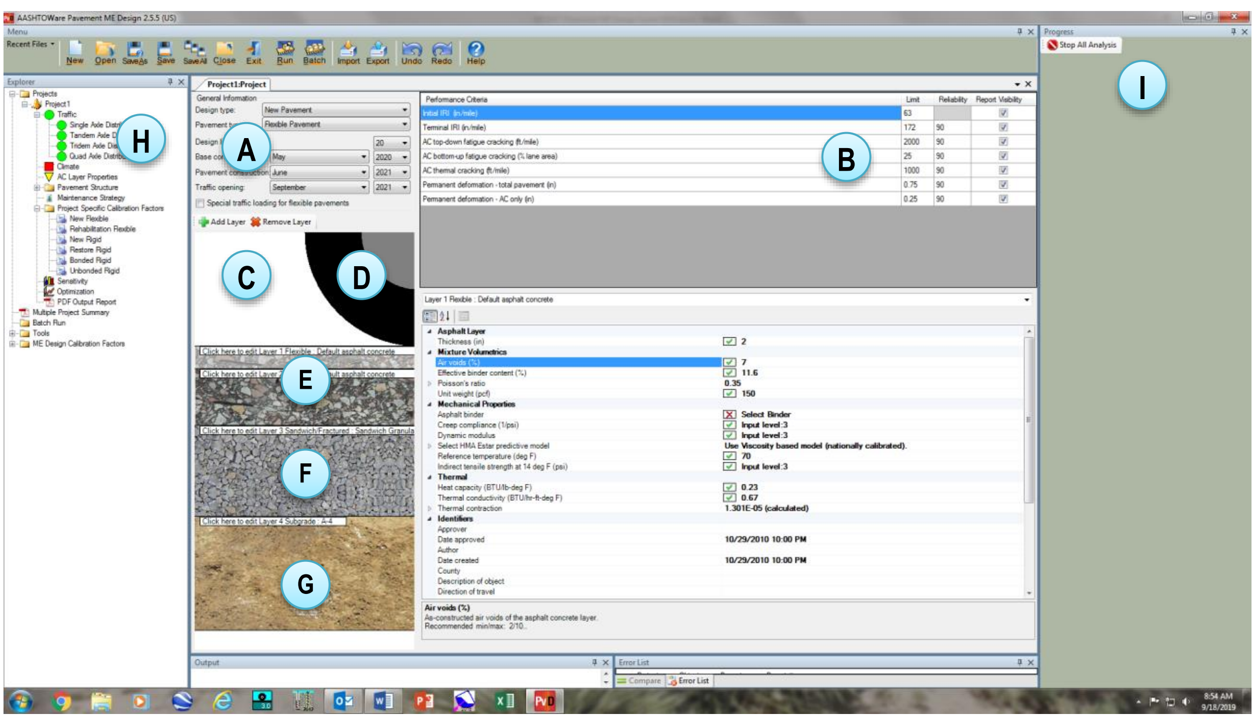


Figure 8. Data Input Screen of Pavement ME Design Program with the added Layers

Table 2. Pavement ME Design Data Input Areas			
Input or Display Area	**Area Label**	**Description**	**Section**
General information	**A**	design type, pavement type, design life, etc.	**A.3.1**
Performance criteria	**B**	distress limits and reliability for each distress type	**A.3.2**
Climate data	**C**	weather station data provided by the program	**A.3.3**
Traffic data	**D**	AADTT, axle configuration, operational speed, etc.	**A.3.4**
Material data	**E**	bound layers: asphalt concrete binder and mix	**A.3.5**
	F	unbound layers: aggregate base course	**A.3.6**
	G	subgrade: resilient modulus, gradation, R-value	**A.3.7**
Project File Tree	**H**	Icons turn to Green from Red when data input is complete	**A.3.8**
Progress	**I**	The progress of computations when running the program	**A.3.9**

A.3.1 General Information

Data input begins with entering **General Information** for the project in **Area A** of the data input screen **(Figure 8)**. The **Design Type** can be either new, overlay, or restoration. The **Pavement Type** can be either flexible pavement, jointed plain concrete pavement (JPCP), continuously reinforced concrete pavement (CRCP), or semi-rigid pavement. Note that most of MCDOT roadways are flexible pavements. Typical **Design Life** for MCDOT roads is 20 years. However, other design lives can be used when dealing with special cases. For example, a 4-year design life is recommended for temporary roadways. The dates of **Base Construction**, **Pavement Construction**, and **Traffic Opening** are also input as general information.

A.3.2 Performance Criteria

Performance Criteria set acceptable limits for various distress types along with an assigned reliability. MCDOT has adopted the national criteria[4], which are shown in **Table 3**. For example, when the International Roughness Index (IRI) exceeds a value of 172, the pavement is considered failed.

Enter the performance criteria in **Area B** of the data input screen (**Figure 8**). A reliability of 95% is used for arterial roads. For collector and local roadway designs, use reliability values of 90% and 80%, respectively. Also, MCDOT may require two sets of performance criteria: one for the design life and another for a half-life for maintenance purposes. These requirements will be included in the scope of services. The designer should contact MCDOT prior to the beginning of design to obtain site specific information.

Table 3. Pavement ME Design Performance Criteria for MCDOT Roads: Arterials, Collectors, and Local Roads					
Distress Type	**Units**	**Limit**	**Reliability**		
			Arterials	Collectors	Local
Initial IRI	in/mile	63	95	90	80
Terminal IRI	in/mile	172	95	90	80
AC Top-Down Fatigue Cracking	ft/mile	2000	95	90	80
AC Bottom-Up Fatigue Cracking	% lane area	25	95	90	80
AC Thermal Cracking	ft/mile	1000	95	90	80
Permanent Deformation-Total pavement	in	0.75	95	90	80
Permanent Deformation-AC Only	in	0.25	95	90	80

A.3.3 Climate Data

Once the general project information and design criteria are entered, **Project Climate** data input can begin by clicking on Area **C** of the data input screen (**Figure 8**) or double clicking on Climate in the Explorer tab. When Area **C** is clicked, a new window called **Climate** will appear (**Figure 9**).

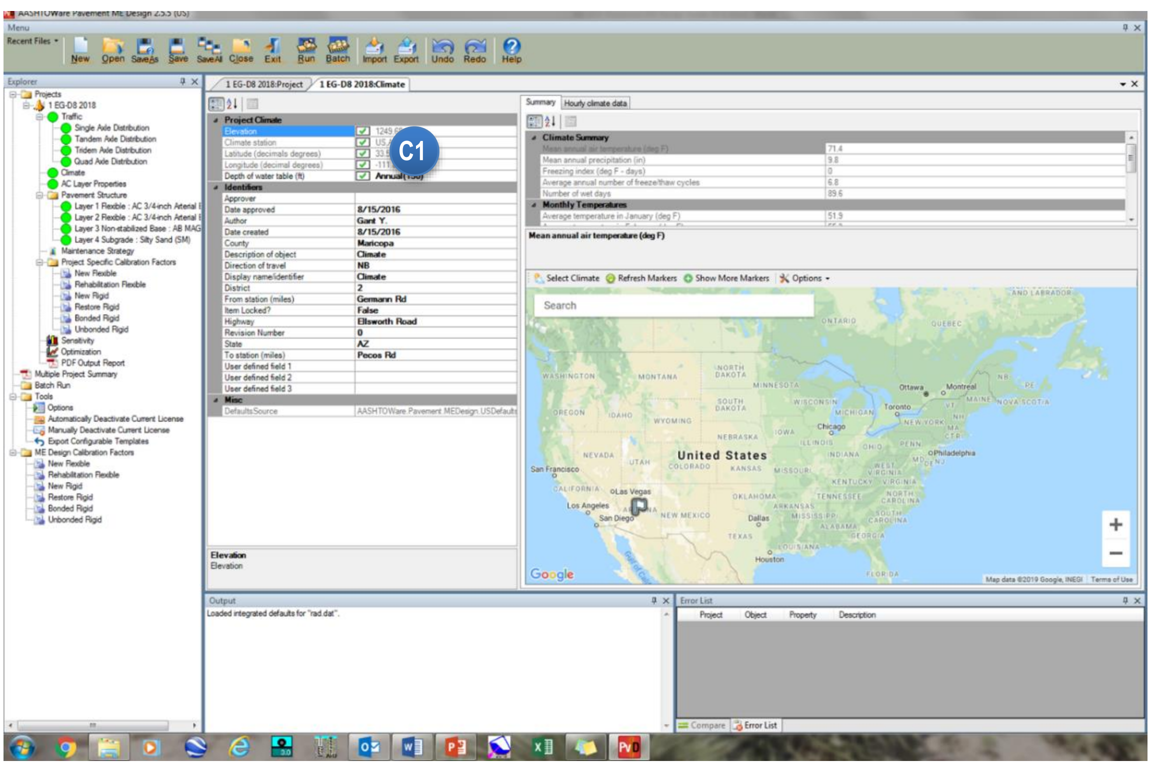


Figure 9. Climate Data Input Screen of Pavement ME Design Software

The program allows the user to search any desired region in the United States (for example, Phoenix, AZ), and to select a marker on the map containing climate data (**Figure 10**). Once a marker is selected, the corresponding data (Elevation, Climate station, Latitude, and Longitude) are populated in to the respective data cells in Area **C1** (**Figure 9**). Historic climate data available for the selected location will be used by the program in the analysis. The depth to groundwater table can also be input on Climate screen. If no site specific groundwater information is available, use the Arizona Department of Water Resources (ADWR) Well Registry to obtain groundwater depths from the regional well data.

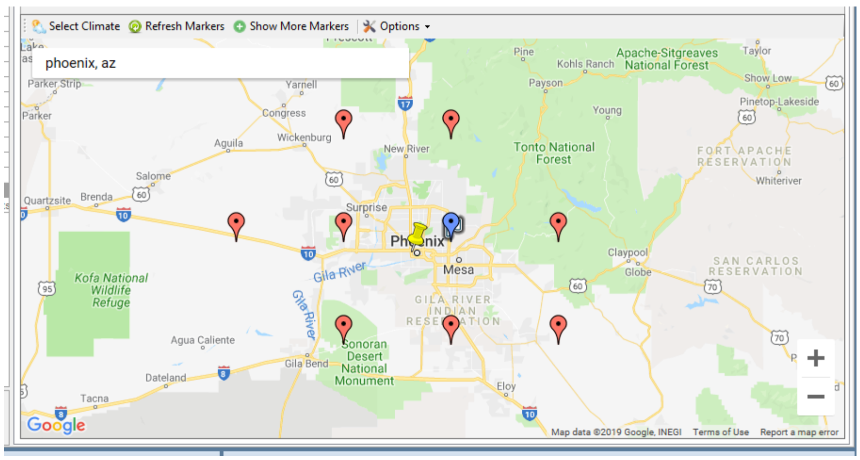


Figure 10. Climate Data Markers that appear on the Map for Phoenix, AZ

A.3.4 Traffic data

Traffic data input can begin by clicking on Area **D** of the data input screen (**Figure 8**). When Area **D** is clicked, a new window called **Traffic** will appear. The types of traffic data to be input are listed in **Table 4** and shown in **Figure 11**.

Table 4. Traffic Data

Main Data Type	Description	Area	Section
AADTT	Average Annual Daily Truck Traffic	**D1**	A 3.4.1
Traffic capacity	Capacity cap, if desired	**D2**	A 3.4.2
Axle Configuration	Axle width, spacing, and tire pressure	**D3**	A 3.4.3
Lateral Wander	Lane width, wheel location, and standard deviation for lateral wander	**D4**	A 3.4.4
Wheelbase	Spacing and % trucks corresponding to short, medium, and long truck categories	**D5**	A 3.4.5
Vehicle Class Distribution and Growth	% distribution of trucks among Class 4 through Class 13, growth rate, and growth function	**D6**	A 3.4.6
Monthly Adjustment	Monthly adjustment, if data is available	**D7**	A 3.4.7
Axles per Truck	Average values for single, tandem, tridem, and quad axles for Class 4 through Class 13 trucks	**D8**	A 3.4.8

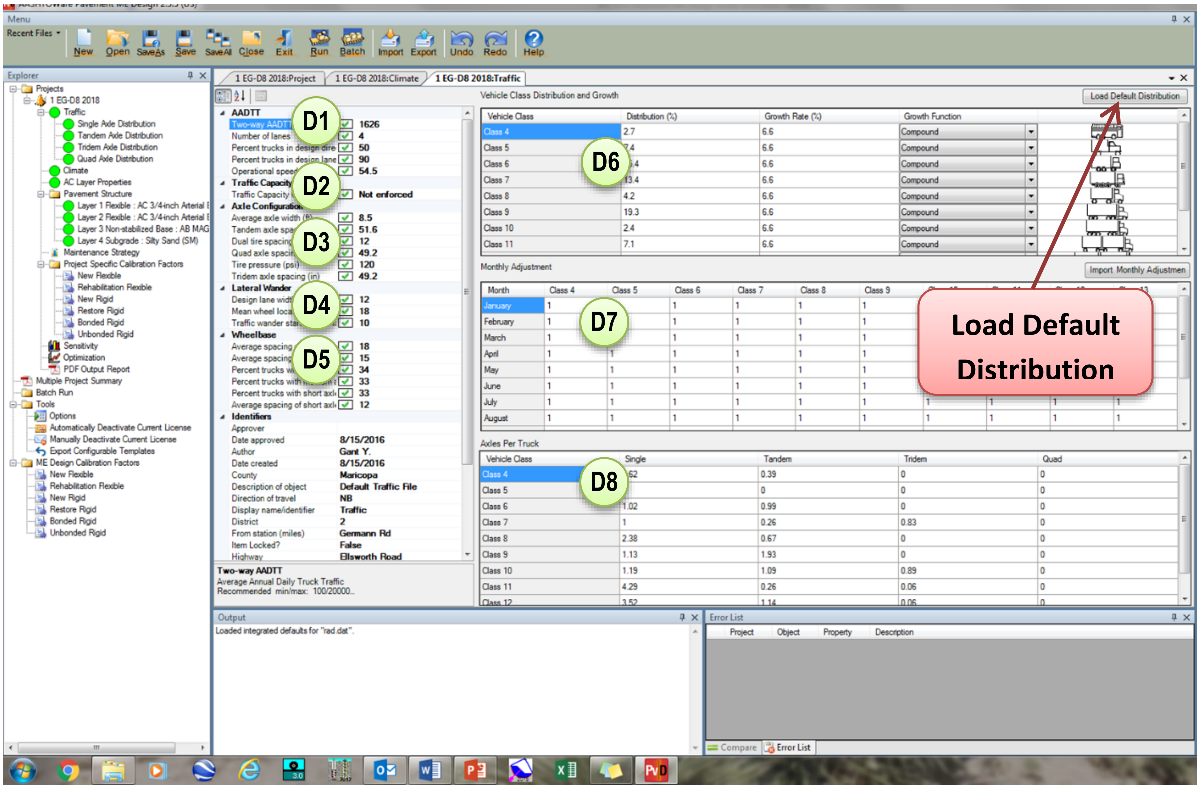


Figure 11. Traffic Data Input Screen of Pavement ME Design Software

A.3.4.1 AADTT

Average annual daily truck traffic (AADTT) is computed from the average annual daily traffic (AADT) and the percent trucks (T) for the roadway under design. Vehicle classes 4 through 13 (**Figure 12**) are considered as trucks when determining the percent trucks. Refer to Section 10.2.1 in Chapter 10 of RDM for guidance on determining T.

$$\mathrm{AADTT} = \mathrm{AADT} \times \mathrm{T}$$

Number of lanes in the design direction, percent trucks in design direction, percent trucks in design lane, and operational speed are the next inputs. Operational speed is the speed at which drivers are observed operating their vehicles. The 85th percentile of the distribution of observed speeds is the most frequently used descriptive statistic for the operational speed associated with a particular location. The operational speed may vary based on factors such as traffic, weather, location, and time. For MCDOT roads, the operational speed can range between 5 to 10 mph higher than the posted speed limit. These data are input in Area **D1** of the traffic screen (**Figure 11**). Basic traffic count data for Maricopa County roads are available on the [MCDOT website](). Designers can contact MCDOT for other traffic data types.

Pavements exhibit relatively low dynamic moduli when the traffic operational speeds are low, for example at intersections. Low dynamic moduli result in severe rutting conditions. For all designs that include turn lanes or pavements within 500 feet of an intersection, the designer should check the rutting performance by running the program with low operational speeds. If no other information is available, use 10 mph as the intersection operational speed.

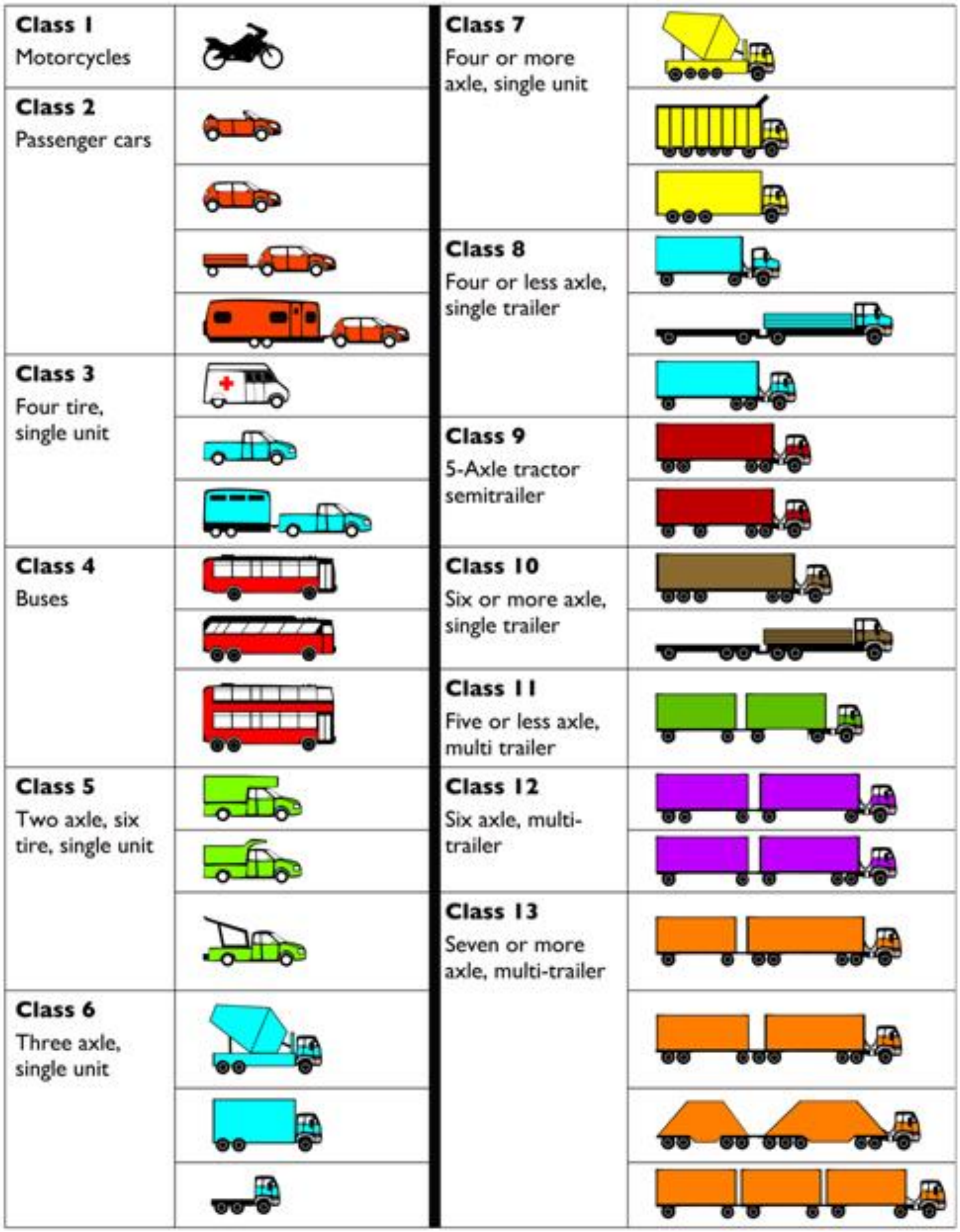


Figure 12. FHWA 13 Vehicle Category Classification

A.3.4.2 Traffic Capacity

Traffic capacity caps can be enforced if desired for a roadway. In general, MCDOT does not enforce traffic capacity caps. Traffic cap is entered in Area **D2** on the traffic screen (**Figure 11**).

A.3.4.3 Axle Configuration

Axle configuration includes dual tire spacing, average axle width, axle spacing for tandem, tridem, and quad tire configurations, and tire pressure as illustrated in **Figure 13**. For MCDOT designs, use the national average values given in **Table 5**. These data are entered in Area **D3** of traffic screen (**Figure 11**).

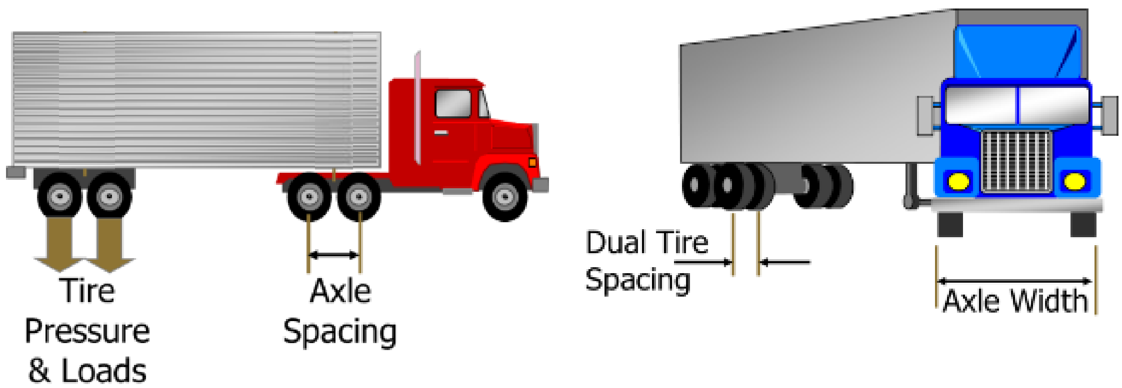


Figure 13. Truck Axle Configuration

Table 5. Axle Configuration		
Parameter	**Units**	**Value**
Average Axle Width	feet	8.5
Dual Tire Spacing	inches	12
Tandem Axle Spacing	inches	51.6
Tridem Axle Spacing	inches	49.2
Quad Axle Spacing	inches	49.2
Tire Pressure	psi	120

A.3.4.4 Lateral Wander

Lateral wander of truck wheels affect the rutting depth of the pavement. If wheels are concentrated on a narrow wheel path, lateral wander is relatively small, the depth of rutting will be higher. Conversely, if the lateral wander is relatively large, the resulting rutting depth is lower. For MCDOT designs, use the national average values given in **Table 6**. These data are entered into Area **D4** of the traffic screen (**Figure 11**).

Table 6. Lateral Wander		
Parameter	**Units**	**Value**
Design Lane Width	Feet	12
Mean Wheel Location	Inches	18
Traffic Wander Standard deviation	Inches	10

A.3.4.5 Wheelbase

The wheelbase is the axle to axle distance as shown in **Figure 14**. The wheelbase can have three values corresponding to long, medium, and short axle types. The percentage of trucks with long, medium, and short wheel bases should be entered in to the program. For MCDOT designs, use the national average values given in **Table 7**. These data are entered into Area **D5** of the traffic screen (**Figure 11**).

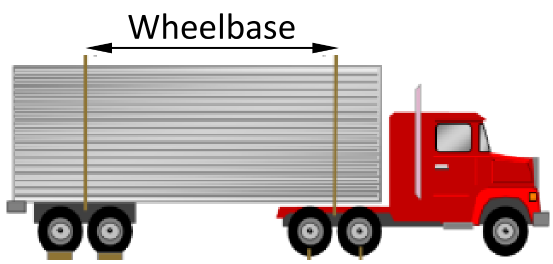


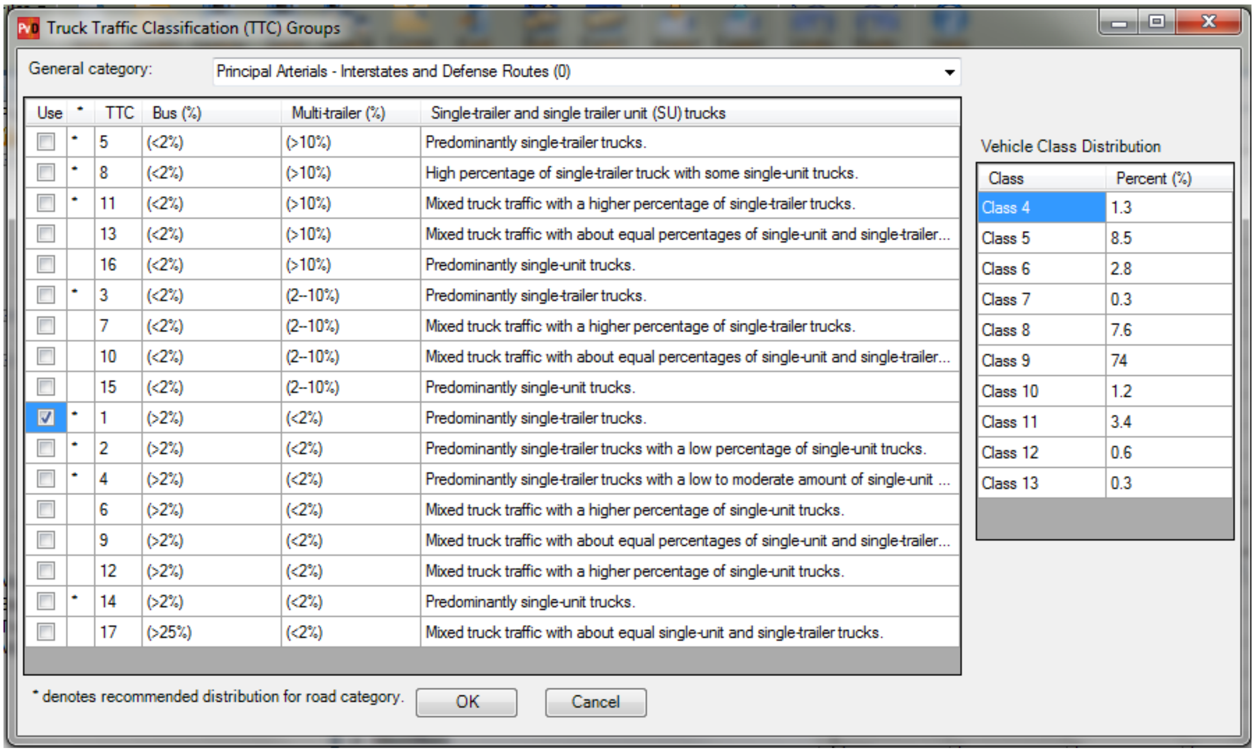
Figure 14. Truck Wheelbase

Table 7. Wheelbase		
Axle Type	Average Spacing (ft.)	Percent Axle Type (%)
Long Axles	18	34
Medium Axles	15	33
Short Axles	12	33

A.3.4.6 Vehicle Class Distribution

The traffic distribution among vehicle classes 4 through 13 is obtained from traffic studies. Currently, MCDOT is in the process of obtaining vehicle class distribution for MCDOT arterials and collector roads. These data will be available for the designers in the near future. The typical national class distributions are provided within the program for the user to select. These default distributions can be loaded by clicking on **Load Default Distribution** button located at the top right corner of traffic screen (**Figure 11**). The screen shown on **Figure 15** will appear when **Load Default Distribution** button is clicked and the embedded drop down menu will give six options:

1. Principal Arterials - Interstates and Defense Routes
2. Principal Arterials - Other
3. Minor Arterials
4. Major Collectors
5. Minor Collectors
6. Local Routes and Streets



Use	*	TTC	Bus (%)	Multi-trailer (%)	Single-trailer and single trailer unit (SU) trucks
☐	*	5	(<2%)	(>10%)	Predominantly single-trailer trucks.
☐	*	8	(<2%)	(>10%)	High percentage of single-trailer truck with some single-unit trucks.
☐	*	11	(<2%)	(>10%)	Mixed truck traffic with a higher percentage of single-trailer trucks.
☐		13	(<2%)	(>10%)	Mixed truck traffic with about equal percentages of single-unit and single-trailer...
☐		16	(<2%)	(>10%)	Predominantly single-unit trucks.
☐	*	3	(<2%)	(2-10%)	Predominantly single-trailer trucks.
☐		7	(<2%)	(2-10%)	Mixed truck traffic with a higher percentage of single-trailer trucks.
☐		10	(<2%)	(2-10%)	Mixed truck traffic with about equal percentages of single-unit and single-trailer...
☐		15	(<2%)	(2-10%)	Predominantly single-unit trucks.
☑	*	1	(>2%)	(<2%)	Predominantly single-trailer trucks.
☐	*	2	(>2%)	(<2%)	Predominantly single-trailer trucks with a low percentage of single-unit trucks.
☐	*	4	(>2%)	(<2%)	Predominantly single-trailer trucks with a low to moderate amount of single-unit ...
☐		6	(>2%)	(<2%)	Mixed truck traffic with a higher percentage of single-unit trucks.
☐		9	(>2%)	(<2%)	Mixed truck traffic with about equal percentages of single-unit and single-trailer...
☐		12	(>2%)	(<2%)	Mixed truck traffic with a higher percentage of single-unit trucks.
☐	*	14	(>2%)	(<2%)	Predominantly single-unit trucks.
☐		17	(>25%)	(<2%)	Mixed truck traffic with about equal single-unit and single-trailer trucks.

Vehicle Class Distribution

Class	Percent (%)
Class 4	1.3
Class 5	8.5
Class 6	2.8
Class 7	0.3
Class 8	7.6
Class 9	74
Class 10	1.2
Class 11	3.4
Class 12	0.6
Class 13	0.3

Figure 15. Default Distributions Available in Pavement ME Design

These data are entered in or loaded into Area **D6** of the traffic screen (**Figure 11**). If no site specific data is available, select a representative distribution for MCDOT projects from the list after discussing with MCDOT.

A.3.4.7 Growth Rate and Growth Function

Traffic in the growing or developing areas of Maricopa County has experienced growth in the range of 4% to 8% annually in recent years. More mature areas experience less growth (in the range of 0% to 4%). The designer should recognize the significance of this factor on the design. Growth rates are one of the most influential factors in the final thickness of the pavement, and they should be selected as accurately as possible after consulting with MCDOT.

The growth rate for County roads is obtained from Maricopa County Association of Governments (MAG)[5] projections available at the time of design. Consult with MCDOT to receive the latest growth rate information. Unless any other supporting data are available, select compound growth function. These data are entered into Area **D6** of the traffic screen (**Figure 11**).

A.3.4.8 Monthly Adjustment

Monthly adjustment factors will allow using site specific variation of traffic conditions on monthly basis. In other words, this will allow the designer a way to handle significant seasonal variations in truck traffic such as the conditions observed in farming communities. If no site specific data is available, populate the table with a value of 1.0 as the factor, as shown on **Table 8**. The monthly adjustment is entered into Area **D7** of the traffic screen (**Figure 11**).

Table 8. Monthly Adjustment

Month	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13
January	1	1	1	1	1	1	1	1	1	1
February	1	1	1	1	1	1	1	1	1	1
March	1	1	1	1	1	1	1	1	1	1
April	1	1	1	1	1	1	1	1	1	1
May	1	1	1	1	1	1	1	1	1	1
June	1	1	1	1	1	1	1	1	1	1
July	1	1	1	1	1	1	1	1	1	1
August	1	1	1	1	1	1	1	1	1	1
September	1	1	1	1	1	1	1	1	1	1
October	1	1	1	1	1	1	1	1	1	1
November	1	1	1	1	1	1	1	1	1	1
December	1	1	1	1	1	1	1	1	1	1

A.3.4.9 Axles per Truck

MCDOT is in the process of obtaining vehicle class distribution for MCDOT arterials and collector roads. In addition to the class distribution, the axles per truck values for the County will be obtained from the countywide traffic study, which is in progress. These data will be available for the designers in the near future. The default national data values given in **Table 9** should be used, if no other data are available. Axles per truck are entered into Area **D8** of the traffic screen (**Figure 11**). Note that trucks with quad axles are rarely encountered on County roads, and therefore, all the values are set to zero.

Table 9. Axles Per Truck

Vehicle Class	Single	Tandem	Tridem	Quad
Class 4	1.62	0.39	0.00	0.00
Class 5	2.00	0.00	0.00	0.00
Class 6	1.02	0.99	0.00	0.00
Class 7	1.00	0.26	0.83	0.00
Class 8	2.38	0.67	0.00	0.00
Class 9	1.13	1.93	0.00	0.00
Class 10	1.19	1.09	0.89	0.00
Class 11	4.29	0.26	0.06	0.00
Class 12	3.52	1.14	0.06	0.00
Class 13	2.15	2.13	0.35	0.00

A.3.5 Material Characterization—Bound Layers: AC & ARAC

MCDOT roads are typically designed using flexible pavements. A substantial amount of material characterization is required for asphalt binder, asphalt rubber asphalt concrete (ARAC) mixes, and asphalt concrete (AC) mixes of bound layers. In addition, unbound layers such as aggregate base (AB), treated subgrade (TS), and subgrade materials should be characterized with appropriate tests. The Pavement ME design program identifies the structural layers somewhat differently than the commonly used names and those are shown in **Table 10**.

Table 10. Layer Identification by Pavement ME Design

Common Layer name	MCDOT Designation	Name Assigned by the Program
Asphalt Concrete	AC	Default Asphalt Concrete
Asphalt Rubber Asphalt Concrete	ARAC	Default Asphalt Concrete
Aggregate Base	AB	Non-Stabilized Base
Treated Subgrade	TS	Subgrade
Subgrade	SS	Subgrade
Bedrock	BR	Bedrock

A 3.5.1 Hierarchical Levels

As mentioned in Section A.3, the program accepts data in three hierarchical levels designated Level 1, Level 2, and Level 3. The differences between the levels and the data required for each level are summarized in **Table 11**. Selecting a hierarchical level is not required on climate and traffic screens at the time of this document. The climate data is similar for all three levels. The site specific traffic data can vary from simple and readily available AADTT to more rigorous traffic spectra such as axles per truck information. Even though the program does not identify any levels for traffic, the data entered can be considered fitting into an informal hierarchical level as explained in **Table 11**. Actual hierarchical level selections are encountered when entering material data as described in **Table 12**.

As mentioned earlier, on the material screen, Level 1 represents the most advanced level where the designer can input advanced site specific data from material characterization such as dynamic modulus and resilient modulus of the asphalt mix. On the other hand, Level 3 represents the lowest level where the designer can use readily available data such as sieve analysis and plasticity index along with the default data provided by the program. Level 2 can be used when some intermediate test data are available. For example, instead of inputting direct resilient modulus test data for unbound layers (aggregate base and subgrade), R-value or CBR or other parameters can be input so that the program can internally generate a correlated resilient modulus value.

Figure 16 lists some of the required testing on materials in each layer when carrying out a pavement design. Under the MCDOT research program conducted for local calibration of Pavement ME Design program, numerous tests were conducted and compiled for future use. These test data represent the materials that the County uses most often in pavement structures. Therefore, designers are encouraged to use the data provided in this document to avoid rigorous, expensive testing.

Table 11: Hierarchical Levels in Pavement ME Design			
Level	**Data Type**	**Required Data**	**Remarks**
1	Climate	All levels share the same data.	No level selection.
	Traffic	• All levels share the same data. • Full data set includes AADTT, axle configuration, lateral wander, wheelbase, vehicle class distribution, monthly adjustment, and axles per truck. • It can be interpreted that if site specific data are used for all of the above areas, the analysis is at Level 1.	No level selection.
	Materials	See **Table 12**	
2	Climate	All levels share the same data.	No level selection.
	Traffic	• See Level 1 description above. • If site specific data are used for AADTT and only for some of other types of data, then the analysis can be considered as Level 2.	No level selection.
	Materials	See **Table 12**	
3	Climate	All levels share the same data	No level selection.
	Traffic	• See Level 1 description above. • AADTT is the only site specific data used and all the other data are from the national averages available in the program, the analysis can be considered as Level 3.	No level selection.
	Materials	See **Table 12**	

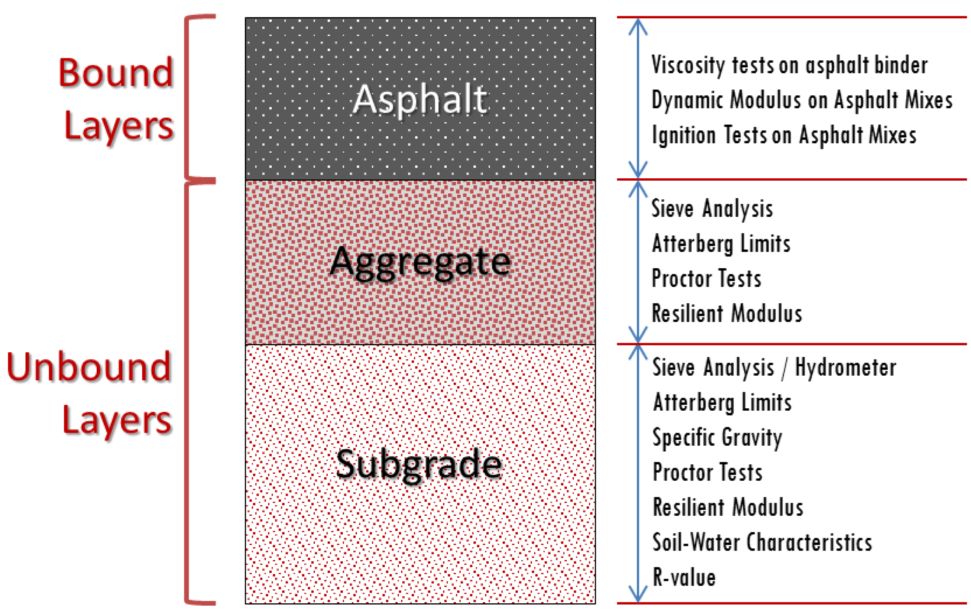


Figure 16. Material Characterization Testing on Various Pavement Layers

Table 12: Hierarchical Levels on Material Screen			
Data	**Input Properties or Information**		
	Level 1	**Level 2**	**Level 3**
Asphalt Layer	Thickness (inches)	Same as Level 1	Same as Level 1
Mixture Volumetrics	Air Voids (%) Effective Binder Content (%) Poisson's Ratio Unit Weight (pcf)	Same as Level 1	Same as Level 1
Mechanical Properties: **Asphalt Binder**	**Superpave Performance Grade:** Not available with v 2.5.5	**Superpave Performance Grade:** Same as Level 1	**Superpave Performance Grade:** Select Binder Type from the dropdown menu. Example: PG 70-16
	Conventional–Penetration/Viscosity Grade: - Softening Point at 13,000 Poise (°F) - Absolute Viscosity at 140 °F (Poise) - Kinematic Viscosity at 275 °F (cS) - Specific Gravity at 77 °F - Penetration at 77 °F (1/10 mm) - Brookfield Viscosity at: 212, 250, 275, 300, 350 °F (cP)	**Conventional–Penetration/Viscosity Grade:** Same as Level 1, although some of the properties can be entered from available data (i.e. not from actual test data)	**Viscosity Grade:** Select Binder Type from the dropdown menu. Example: AC 30 **Penetration Grade:** Select Binder Type from the dropdown menu. Example: Pen 80-100
Mechanical Properties: **Creep Compliance**	Enter test data at – 4°F, 14°F and 32°F where these temperatures are identified as low, medium, and high temperatures. The creep compliance at these three temperatures should be tested for 7 different time periods (1, 2, 5, 10, 20, 50, and 100 seconds)	Enter test data only at medium temperature, 14°F. The creep compliance at this temperature should be tested for 7 different time periods (1, 2, 5, 10, 20, 50, and 100 seconds)	Use program provided creep compliance data.
Mechanical Properties: **Dynamic Modulus & Reference Temperature**	- Dynamic Modulus is E* measured in psi. The test should be carried out for 5 different temperatures at 6 different frequency values. The test data is entered into a table provided within the program. - Note: G* based model is not available yet. - Reference temperature is always 70 °F.	No E* values are entered. Instead, enter gradation data of aggregates used in the mix. The program will internally generate the master curve that represents the E* values required for the analysis.	Same as Level 2
Mechanical Properties: **Indirect Tensile Strength**	Input data obtained from a test conducted at 7 different temperatures.	Input data obtained from a test conducted at 4 different temperatures.	Use the program provided data.
Thermal	Enter Heat Capacity (BTU/lb-°F) of AC and the thermal conductivity (BTU/hr-ft-°F) of AC surface based on agency historical data. Then, program will calculate the Thermal Contraction of AC.	Same as Level 1	Same as Level 1

The bound layers may consists of multiple asphalt layers: asphalt-rubber mix, ½-inch asphalt mix, and ¾-inch asphalt mix. The design process requires selecting suitable layer thicknesses for ARAC, AC, and AB, and running the Pavement ME Design program to determine the predicted distresses. The mechanistic principles adopted in the Pavement ME design assume that pavement can be modeled as a multi-layered elastic structure system as illustrated in **Figure 17**, where δ is the pavement deflection, ϵ_c is the compressive strain, and ϵ_t is the tangential strain.

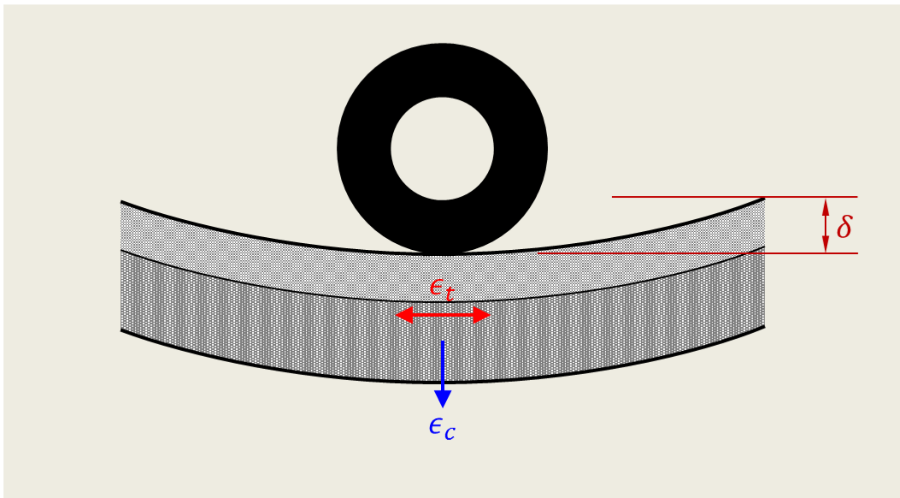


Figure 17. Mechanistic Principle

MCDOT roads are designed using Superpave mixes adhering to the aggregate gradation criteria specified in the MCDOT Supplement to MAG Specifications[6]. The MCDOT gradation criteria was established to ensure proper degree of interlocking (DOI) in the aggregate mix. It has been found that if DOI is less than 85% the pavement is more prone to premature transverse (durability) cracking, and therefore, DOI should be kept above 85%. DOI is defined as the ratio of volume of coarse aggregate in the mix to the volume of coarse aggregate in loss unit weight state.

The tests and data required for each hierarchical level are discussed in the flowing respective sections.

A.3.5.2 Asphalt Layer

Typically, MCDOT uses three main types of asphalt concrete mixes in pavement design: ARAC, ¾-inch AC, and ½-inch AC. The data provided here are mainly for those three mixes. Note that the AC layers are subdivided to satisfy the constructability requirements in Section 710 of the MAG Specification[7].

The first asphalt layer input parameter is the layer thickness entered in Area **E1** of the material data screen (**Figure 18**) by clicking on the layer below the tire symbol. Refer to Section A.3 on starting a new project and adding different layers to the program.

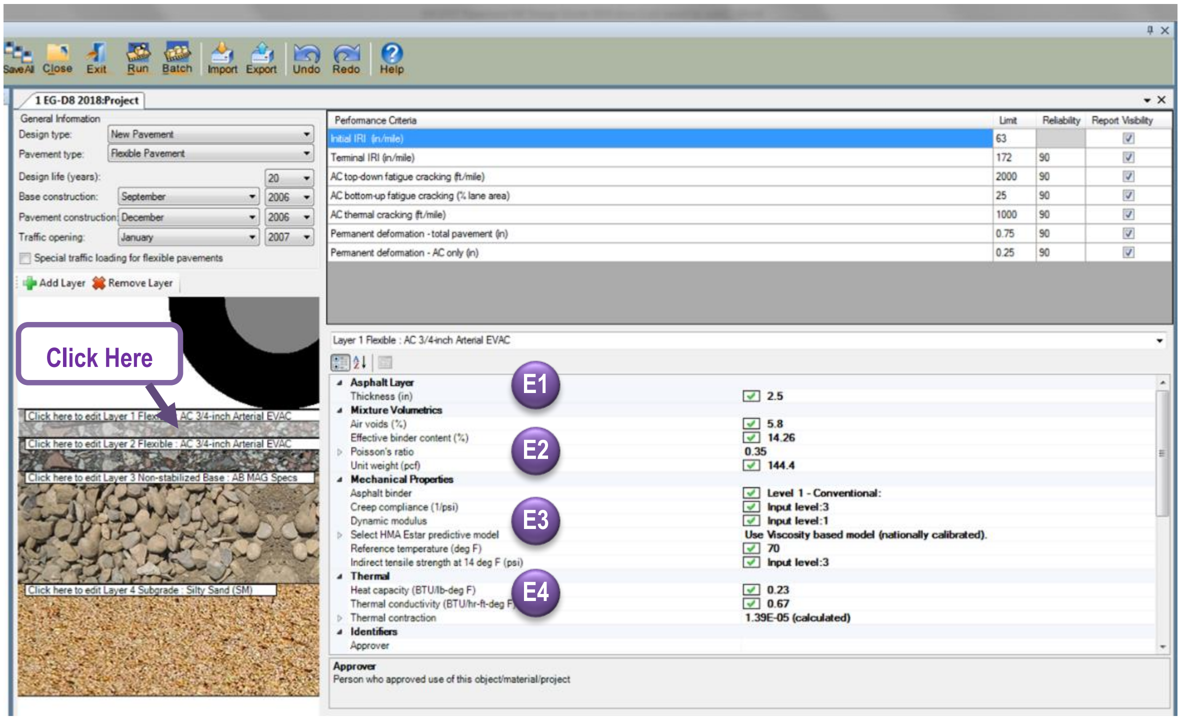
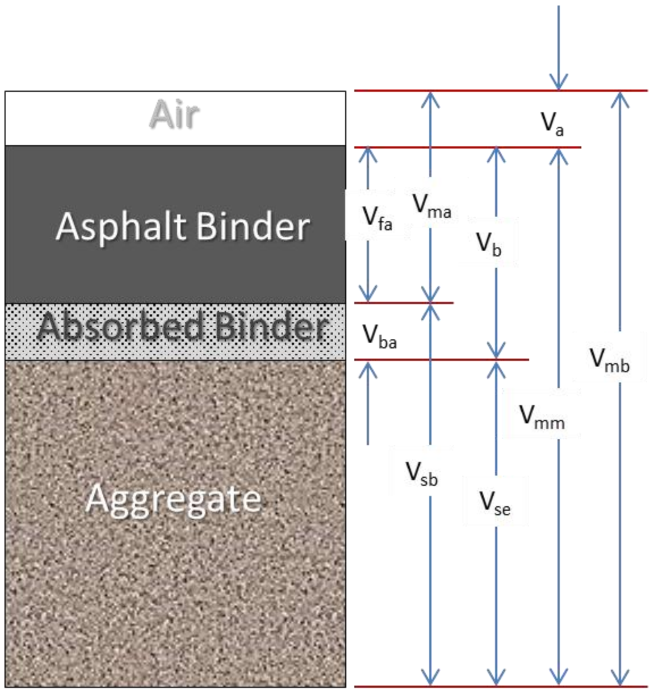


Figure 18. Material Data (Asphalt Concrete) Input Screen of Pavement ME Design Software

A.3.5.3 Mixture Volumetrics

Mixture volumetrics are an important set of inputs entered in Area **E2** of the material data screen (**Figure 18**). The mixture volumetrics include air voids, effective binder content by volume, Poisson's ratio, and unit weight of the asphalt mix. **Figure 19** shows a component diagram of compacted Hot Mix Asphalt (HMA) specimen that defines various volumetric parameters.

The effective volumetric binder content is a computed parameter based on the mixture properties and weight-based binder content. The user may have limited experience using the volumetric binder content. The common weight-based binder contents and corresponding volumetric binder contents are shown in **Table 13** for user to adopt in the design.



V_{ma} = volume of voids in mineral aggregate

V_{mb} = bulk volume of compacted mix

V_{mm} = voidless volume of paving mix

V_{fa} = volume of voids filled with asphalt binder

V_a = volume of air voids

V_b = volume of asphalt

V_{ba} = volume of absorbed asphalt binder

V_{sb} = volume of mineral aggregate by bulk specific gravity

V_{se} = volume of mineral aggregate by effective specific gravity

Figure 19. Component Diagram of Compacted Hot Mix Asphalt (HMA) Specimen

$$V_{ma} = 100 - \frac{G_{mb}}{G_{sb}}(100 - P_b),$$

Where,

G_{mb} = Bulk Specific Gravity of Compacted Mix, and

G_{sb} = Bulk Specific Gravity of Aggregate

P_b = Percent Binder Content by weight

$$V_{fa} = V_{ma} - V_a$$

Unless specific information is available for design purposes, use the effective volumetric binder content values given in **Table 13** for mix properties for the three different mix types. Contact MCDOT if the mix type is other than the mix types included in **Table 13**.

Table 13. Mix Properties			
	Mix Type		
Parameter	**ARAC**	**¾-Inch AC**	**½-Inch AC**
Weight-Based Binder Content--BC (%)	8.1	5.1	4.8
Air Voids—V_a (%)	7.0	7.0	7.0
Voids in Mineral Aggregates--V_{ma} (%)	16.0	16.5	16.8
Effective Volumetric Binder Content—V_{fa} (%)	**9**	**9.5**	**9.8**
Poisson's Ratio	0.35	0.35	0.35
Unit Weight (pcf)	140	145	145

A.3.5.4 Mechanical Properties

The mechanical properties of asphalt binder includes asphalt binder properties, creep compliance, dynamic modulus, and indirect tensile strength. This information is entered in Area **E3** of the material data (AC) screen (**Figure 18**). Each property is discussed in detail in the following sections.

A.3.5.4.1 Asphalt Binder

The type of testing and data to be input for asphalt binder are dependent on the hierarchical level of the design (Level 1, Level 2, or Level 3) as shown on **Table 14**. The hierarchical level for asphalt binder is dictated by the hierarchical level selected for the dynamic modulus of the mix. Note: This gives an out of order sequence of data input in the program, and therefore, correcting the order of data input has been requested by MCDOT from the program developer, ARA.

Table 14. Asphalt Binder Data		
Hierarchical Level	**Data Type**	**Remarks**
Level 1	Conventional: Penetration/Viscosity Grade	Adopt this method
	Superpave: Superpave Performance Grade	Program does not support this yet
Level 2	Conventional: Penetration/Viscosity Grade	Adopt this method
	Superpave: Superpave Performance Grade	Program does not support this yet
Level 3	Superpave Performance Grade	Select grade from drop down menu
	Viscosity Grade	Select grade from drop down menu
	Penetration Grade	Select grade from drop down menu

In Level 1, the Superpave Performance Grade model uses G* based model where G* is defined as the complex shear modulus of asphalt binder measured at the test temperature. This model is currently not available with the program, and therefore, the users should select Conventional (Penetration/Viscosity Grade) model when doing a Level 1 design.

Binder properties required by the Penetration/Viscosity Grade model includes softening point, absolute viscosity, kinematic viscosity, specific gravity, penetration, and Brookfield viscosity data (at five different temperatures). The model uses the data to generate a viscosity curve defined by the intercept, **A**, and slope, **VTS**, or the Viscosity-Temperature Susceptibility curve (ASTM D2493 A-VTS relationship of the binder). An example of a viscosity curve is shown in **Figure 20**.

Average properties for asphalt binders typically used in Maricopa County are presented in **Table 15**. If no site specific data is available, use the data provided in **Tables 15** for Level 1 or Level 2 designs.

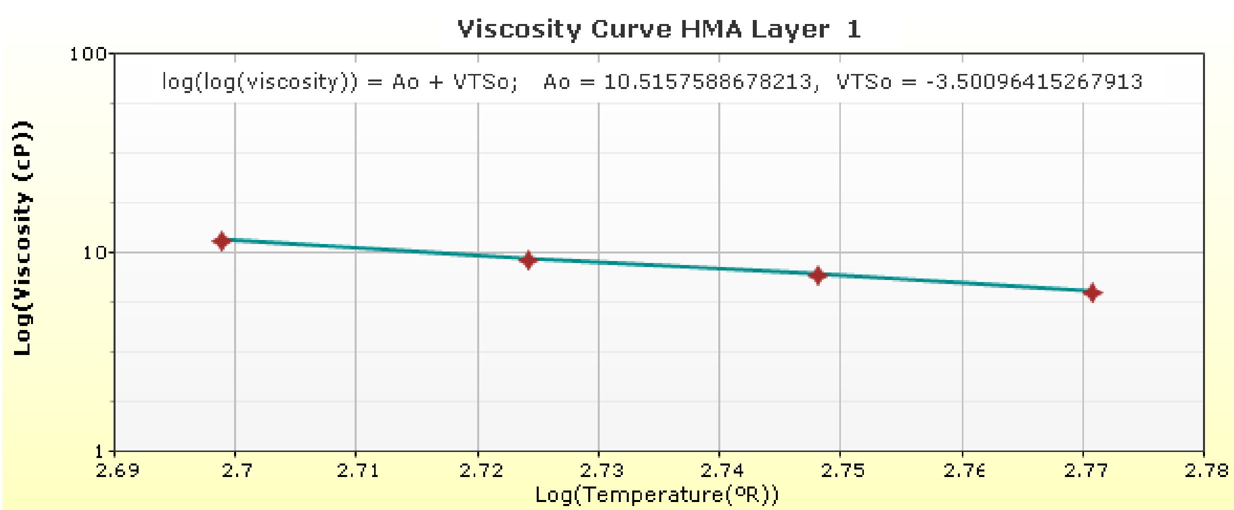


Figure 20. Sample Viscosity Curve generated by Pavement ME Design Program

When conducting a Level 3 design, select the desired Superpave Performance Grade, Viscosity Grade, or Penetration Grade from the drop down menu. The program will assign correlated A and VTS values available inside the program. For example, if Superpave Grade PG 70-10 is selected, the correlated values will be: A = 10.69 and VTS = − 3.566.

In the event that binders different than the 3 described above are used, and binder test data is not available, the binder properties should be established using Level 3 input.

Table 15. Typical Asphalt Binder Properties—Level 1 (Penetration/Viscosity Grade)					
Parameter		**Units**	**ARB**	**PG 70-10**	**PG 76-22 TR**
Softening Point at 13,000 Poise		°F	148	141	149
Absolute Viscosity at 140 °F		Poise	114,200	14,200	146,600
Kinematic Viscosity at 275 °F		centi Stokes	68,330	800	65,150
Specific Gravity at 77 °F		--	1.03	1.03	1.03
Penetration at 77 °F (0.1 mm)		$\frac{1}{10}$ mm	18.6	21.5	16.1
Brookfield Viscosity					
	at 212 °F	centi Poise	271,600	10,120	431,000
	at 250 °F	centi Poise	127,240	2,200	197,000
	at 275 °F	centi Poise	70,260	820	67,100
	at 300 °F	centi Poise	38,420	400	39,400
	at 351 °F	centi Poise	14,440	100	16,800

A.3.5.4.2 Creep Compliance (Mix)

Mix creep compliance data is required for thermal cracking model, and the data is entered in Area **E3** of the material data (AC) screen (**Figure 18**). Again, the type of testing and data are dependent on the hierarchical level of the design (Level 1, Level 2, or Level 3).

In Level 1, creep compliance test is performed at three different temperatures: low (– 4 °F); mid (14 °F); and high (32 °F), for seven loading times (1, 2, 5, 10, 20, 50, and 100 sec.). A sample data table is shown in **Table 16**.

Table 16. Sample Data: Creep Compliance—Level 1 ($\times 10^{-6}$ 1/psi)			
Loading Time (sec)	Low Temperature	Mid Temperature	High Temperature
	– 4 °F	14 °F	32 °F
1	18.0	34.8	51.8
2	19.7	40.2	67.8
5	22.1	48.8	87.3
10	24.1	56.5	109.0
20	26.3	65.3	137.0
50	29.5	79.2	185.0
100	32.2	91.7	231.0

In Level 2, the creep compliance is carried out only at the mid temperature, 14 °F. In Level 3, the data areas will be populated with creep compliance data available in the program. For county projects, use Level 3, if no other data is available.

NOTE: The current thermal cracking model was primarily developed for cold regions, and therefore, it is not fully applicable to warm climatic conditions in Maricopa County. The program development team mentioned in an October 2019 webinar that this issue was taken into consideration to come up with a suitable model. It was also mentioned that the thermal cracking will affect the IRI prediction, and therefore, it cannot be completely ignored. MCDOT's temporary solution to this issue is to adjust the thermal cracking calibration factors to obtain somewhat reasonable predictions for MCDOT roads. Contact MCDOT for guidance on handling thermal cracking in the design.

A.3.5.4.3 Dynamic Modulus (Mix)

Dynamic modulus is the ratio of stress to strain of a material under cyclic loading. This test is one of the most important tests in mechanistic-empirical design. The test provides the dynamic modulus (E*) of the mixes at various temperatures and different loading times. Since asphalt mixes are visco-elastic in nature, the dynamic modulus is expressed as a complex number: $E^* = E_1 + iE_2$. **Figures 21** illustrates the visco-elastic behavior obtained by testing an asphalt mix specimen controlling the temperature and load frequency.

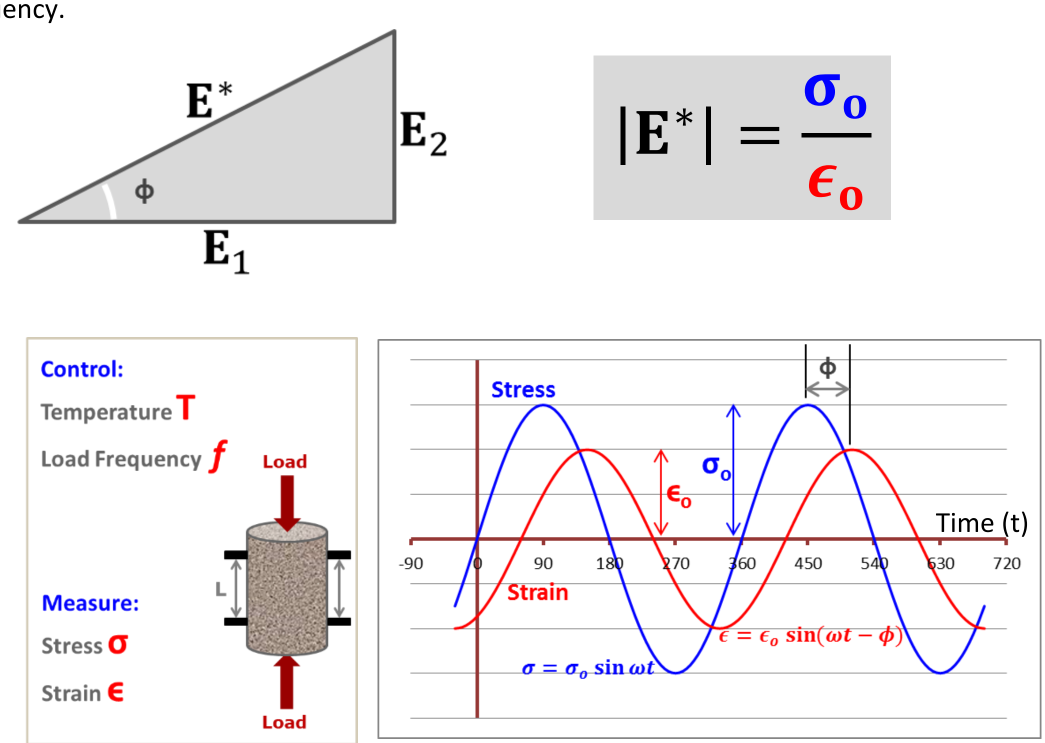


Figure 21. Visco-Elastic behavior of a specimen

σ_0 = maximum stress

ϵ_0 = maximum strain

ω = angular frequency = $2\pi f$

t = time

ϕ = phase angle

The type of data associated with three hierarchical levels is listed in **Table 17**. In Level 1, actual test data is entered and the program will plot the master curve function along with the shift function for the mix. An example master curve and a shift function are shown in **Figure 22** and **Figure 23**, respectively. In Levels 2 and 3, gradation and binder data is correlated to the master curve and shift functions by the program.

Table 17. Dynamic Modulus Data	
Hierarchical Level	**Data Type**
Level 1	Dynamic Modulus at 5 temperatures and 6 frequencies
Level 2	Grain size distribution of aggregates
Level 3	Grain size distribution of aggregates

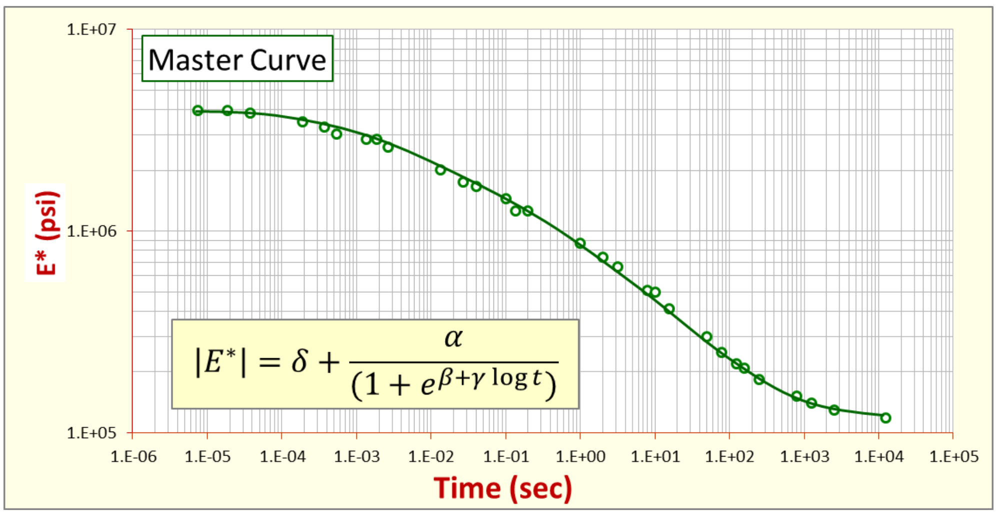


Figure 22. An Example of Master Curve of a Mix

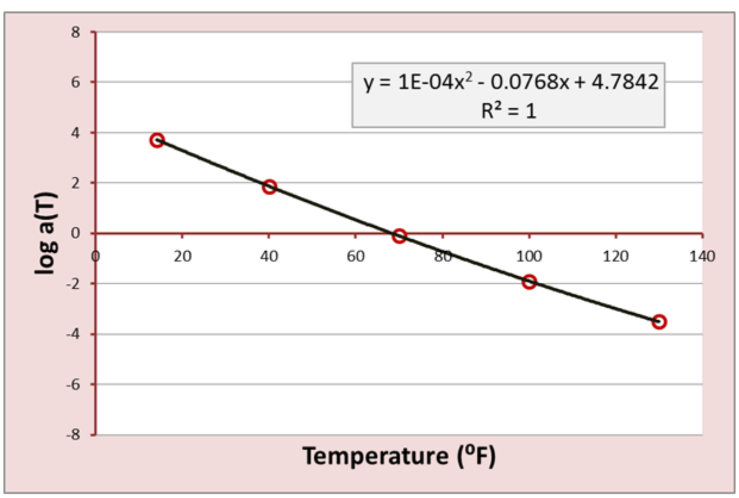


Figure 23. An Example of Shift Function of a Mix

For County pavement designs, average dynamic moduli data are provided for in **Tables 18A, 18B, 18C** and **18D** based on the research data. If no project specific data available for Level 1 designs, use Table 18. For Level 2 and 3 designs, use gradation data of the aggregates used in the mix.

Table 18A. MCDOT Average ARAC Dynamic Modulus, $|E^*|$ (psi)—Level 1

Temperature (^{0}F)	Frequency (Hz)					
	0.1	0.5	1	5	10	25
14	2,627,875	3,052,125	3,222,875	3,618,250	3,790,250	3,984,125
40	1,283,375	1,662,125	1,839,875	2,257,375	2,437,875	2,673,500
70	410,750	616,000	729,625	1,028,875	1,182,625	1,366,500
100	144,125	207,875	250,375	383,500	468,375	605,375
130	81,500	95,125	105,375	147,000	179,250	245,500

Table 18B. MCDOT Average ¾-inch AC Dynamic Modulus, $|E^*|$ (psi)—Level 1 (Performance Grade)

Temperature (^{0}F)	Frequency (Hz)					
	0.1	0.5	1	5	10	25
14	3,796,273	4,262,273	4,456,909	4,850,864	5,001,545	5,108,045
40	1,936,636	2,396,818	2,589,136	3,042,636	3,231,182	3,440,864
70	730,909	1,067,591	1,242,364	1,674,000	1,899,682	2,152,545
100	210,318	338,545	422,409	674,727	823,136	1,048,091
130	90,000	113,545	132,455	204,500	261,000	371,318

Table 18C. MCDOT Average ½-inch AC Dynamic Modulus, $|E^*|$ (psi)—Level 1 (Performance Grade)

Temperature (^{0}F)	Frequency (Hz)					
	0.1	0.5	1	5	10	25
14	4,379,429	4,879,857	5,064,714	5,444,429	5,588,429	5,698,143
40	2,642,143	3,251,429	3,501,571	4,053,429	4,291,571	4,521,286
70	967,857	1,396,000	1,617,000	2,143,143	2,399,857	2,730,286
100	256,143	409,143	507,857	810,286	987,000	1,236,000
130	110,286	139,857	163,000	252,429	318,143	437,000

Table 18D. MCDOT Rubberized Asphalt Dynamic Modulus, $|E^*|$ (psi)—Level 1 (Polymer Modified)**

Temperature (^{0}F)	Frequency (Hz)					
	0.1	0.5	1	5	10	25
14	2,307,000	2,894,000	3,141,000	3,731,000	4,049,000	4,279,000
40	735,000	1,066,000	1,247,000	1,674,000	1,910,000	2,106,000
70	345,000	509,000	612,000	891,000	1,039,000	1,171,000
100	153,000	212,000	249,000	368,000	439,000	560,000
130	79,000	98,000	112,000	159,000	197,000	274,000

**Table 18D contains data from only one single test.

A.3.5.4.4 Reference Temperature

Once the data in **Table 18** are entered, the program will create the master curve based on viscosity-temperature superposition. The creation of master curve requires data shifting around a reference temperature and obtaining a shift factor function. For county projects, input 70 ^{o}F as the reference temperature in Area **E3** of the material data (AC) screen (**Figure 18**).

A.3.5.4.5 Indirect Tensile Strength (Mixture)

Indirect tensile strength (in psi) of the mix at different temperatures is an input in Area **E3** of the material data (AC) screen (**Figure 18**). If project specific data is not available, the program will autofill the indirect tensile strength based on the other mechanical properties entered.

A.3.5.5 Thermal Properties

The thermal properties of the mix include heat capacity, thermal conductivity, and thermal contraction and they are entered in Area **E4** of the material data (AC) screen (**Figure 18**). If no project specific data is available, use the values given in **Table 19** for county projects.

Table 19. Thermal Properties of the Mix

Parameter	Units	Value
Heat Capacity	BTU/lb-^{o}F	0.23
Thermal Conductivity	BTU/hr-ft-^{o}F	0.67
Thermal Contraction	in/in/^{o}F	1.40E-5

A.3.6 Material Characterization—Unbound Layers (AB)

The exact source of aggregate at the time of design may not be available for the designer. Therefore, it is recommended that the MAG Specifications given in Section 702 are used for design purposes. The material data (AB) input screen is shown in **Figure 24**.

A.3.6.1 Unbound—AB

At least 4 inches of aggregate base should be included in the pavement structure. The values for AB layer parameters are input in Area **F1** of the material data (AB) screen (**Figure 24**). Typical values for AB layer parameters are given in **Table 20**.

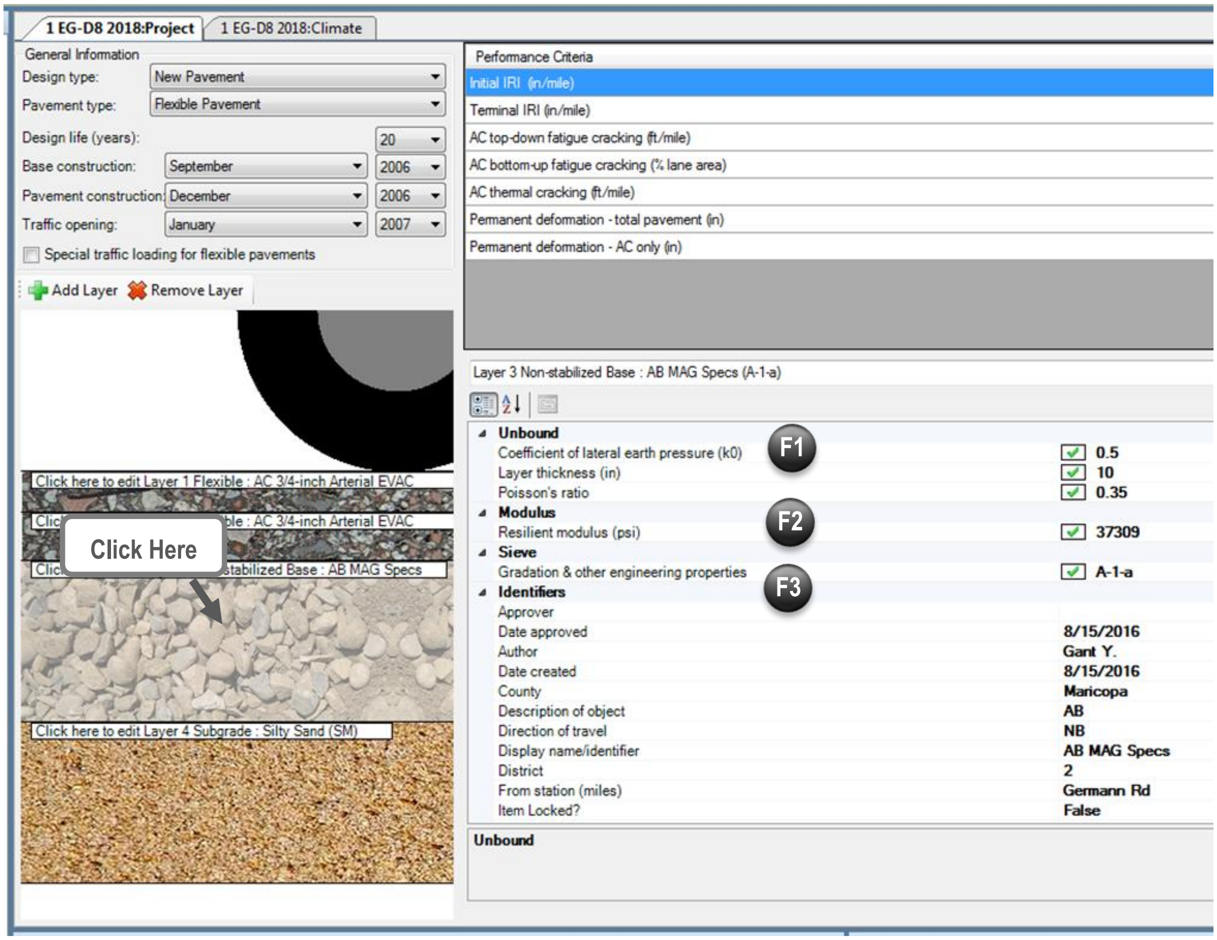


Figure 24. Material Data (AB Layer) Input Screen of Pavement ME Design Software

The 4-inch minimum AB requirement is adopted by considering constructability, base draining, and crack prevention, especially in case of placing AB on relatively hard treated subgrade. Optimization of the pavement layer thicknesses is possible within Pavement ME Design program by clicking **Projects** > **File Name** > **Optimization** > **Optimize Thickness**.

Table 20. Typical AB Layer Parameters

Parameter	Units	Value
Layer Thickness	inches	4 (min.)
Coefficient of Lateral Earth Pressure (k_o)	--	0.5
Poisson's Ratio	--	0.35

A.3.6.2 Modulus—AB

The resilient modulus of unbound AB layer is entered in Area **F2** of the material data (AB) screen (**Figure 24**). The Pavement ME Design program does not currently provide a Level 1 input option for resilient modulus of AB (non-stabilized materials). The only available input levels are Levels 2 and 3 as shown in **Table 21**.

Table 21. Resilient Modulus of AB

Hierarchical Level	Data Type	Remarks
Level 1	Program does not support this yet.	
Level 2	Direct input of resilient modulus	From an actual test.
	Or, input one of the following: 1. California Bearing Ratio (CBR) (%) 2. R-Value 3. Layer Coefficient-a_i 4. Dynamic Cone Penetrometer (DCP) Penetration (in/blow) 5. Based on Plasticity Index (PI) and Gradation	Three analysis types are available to select, as follows: (a) Modify input values by temperature/moisture; or (b) Monthly representative values; or (c) Annual representative values.
Level 3	Direct input of resilient modulus, which can be obtained from a correlation.	Two analysis types are available to select, as follows: (a) Modify input values by temperature/moisture; or (b) Annual representative values.

For MCDOT designs, the preferred method is to use input Level 2, enter R-Value, and select Modify input values by temperature/moisture. Refer to Section 3.7.2 for R-value analysis for a project. If no R-value data is available, select one of the other options.

A.3.6.3 Sieve—AB

Enter gradation and other engineering properties in Area **F3** of the material data (AB) screen (**Figure 24**). Use the values given in **Tables 22** and **Table 23** if no other site specific data is available. The average MAG Specification values are given in **Table 23**. The program asks if the layer is compacted, and the box should be checked "Yes" since the AB layer is always compacted to 100% of the Maximum Dry Density.

Typically, the saturated hydraulic conductivity and soil-water characteristic curve (SWCC) data are not readily available for a soil. Therefore, allow the program to calculate the corresponding values based on other properties entered.

Table 22. Typical Properties of AB		
Property	Units	Value
Liquid Limit (LL)	--	20
Plastic Limit (PL)	--	17
Plasticity Index (PI)	--	3
Maximum Dry Density	pcf	138
Optimum Water Content	%	7
Specific Gravity	--	2.68
Saturated Hydraulic Conductivity	ft./hr	Internally calculated
Soil-Water Characteristic Curve (SWCC)	--	Internally generated

Table 23. MAG Section 702 Gradation Specification for AB (Average)	
Sieve Size	Percent Passing
1.5 in.	100
1 in.	95
No. 4	51
No. 8	42
No. 30	25
No. 200	7

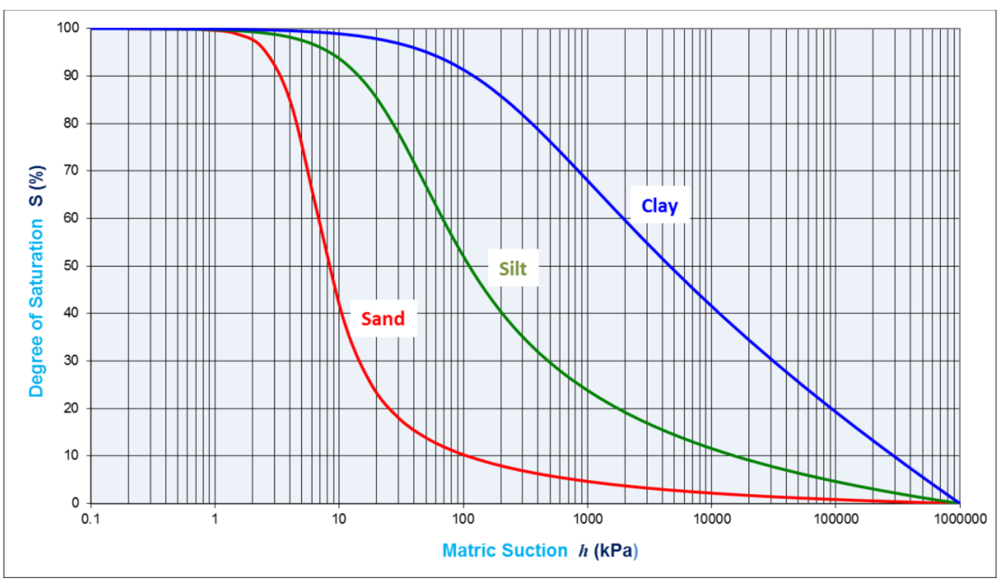


Figure 25. Typical Soil-Water Characteristic Curves

The soil-water characteristic curve (SWCC) is the relationship between degree of saturation, S, and matric suction, h, of the material (soil). When the soil is partially saturated, there is a corresponding negative pore water pressure (in other words matric suction) in the soil depending on the type of soil. The SWCC is sigmoidal in shape when degree of saturation, S (in normal scale), is plotted against matric suction, h (in logarithmic scale). The sigmoidal curve can be described with a four-parameter equation, where the four parameters are a_f, b_f, c_f, and h_r. The program will calculate these four parameters based on the Atterberg Limits and the gradation information of the subgrade. Typical SWCCs for sand, silt and clay are shown in **Figure 25**.

A.3.7 Material Characterization—Unbound Layers (Subgrade)

Prior to any MCDOT roadway project, a geotechnical investigation should be carried out to determine the subsurface conditions at the site. The MCDOT Roadway Design Manual (RDM) provides the guidelines. The same information is echoed here for the user's convenience.

A 3.7.1 Field Data

A 3.7.1.1 Initial Site Visit

During this initial inspection of the project, the design engineer should:

1) Determine the scope of the field sampling,
2) Begin to assess the potential distress mechanisms for existing pavements, and
3) Identify preliminary pavement design alternatives.

As part of this activity, subjective information of distress, road roughness, and moisture/drainage problems should be gathered. Unless traffic volume is a hazard, this data can be collected without any traffic control, through both "windshield" and road shoulder observations. In addition, an initial assessment of traffic control options, obstructions, and safety aspects shall be made during this visit.

The initial site visit has the following impacts on the scope of the subsequent primary field exploration:

- Distress observations may help identify the collection interval, the number of surveyors, and any additional measurement equipment that might be required.
- A general roughness assessment may dictate the need for a more rigorous measurement program to address ride quality related problems, such as differential sags or swells.
- Observation of moisture/drainage problems (e.g., standing water on pavement or ditches, settlement at transverse cracks, raveling in non-trafficked areas, and so on) may indicate the need for a more thorough investigation of subsurface drainage conditions.
- Establishment of the sampling plan for the investigation.

A 3.7.1.2 Field Exploration

Field exploration is to be performed after establishment of an initial roadway profile grade. The essential data collection activities included in this important activity include:

- Distress and drainage surveys

- Observation of land use and geologic features
- Drilling and subsurface geotechnical investigations
- Field sampling and testing

The minimum number of test holes and samples shall be in accordance with **Table 24**. Scoping and Design Report (SDR) investigations shall use the “preliminary” sample frequencies. The “final” sample frequencies shall be the minimum sampling acceptable in reports prepared for final design.

The final design shall incorporate the preliminary test results and other previously gathered information. The engineer shall add test holes and samples so that the number of tests accumulated from the preliminary and final investigation achieve the “final” sample frequencies identified in **Table 24**. An example of the tests needed to meet the “final” sample frequencies for a typical two-mile long project is presented in **Table 25**.

Each test hole shall be advanced to a depth of at least five feet (5’) and extend at least 36 inches below the elevation of the proposed subgrade. In areas of significant cut or fill, the Engineer shall use professional judgment to determine the depth of each test hole. The test-hole depth is intended to sample and test materials located a minimum of 3 feet below the final roadway’s subgrade. Additional test holes shall be taken at apparent changes in soil type.

Coring and sampling of existing pavements is carried out to produce an accurate representation of existing pavement structure. The location of test holes in existing pavements shall be varied to yield samples in the inside and outside lanes and from lanes in both directions. This is especially important in providing design recommendations for rehabilitation or widening projects where the existing pavement may be incorporated into the new structural pavement section.

Sampling frequencies for other tests will be based on specific needs of the project. Percolation testing is required for storm water detention/retention design. Classification type testing ($Sieve$ and PI) is required to address erosion and/or slope stability concerns. Direct shear tests are required to develop foundation design recommendations.

If subgrade soil beneath the designed pavement structure exhibits in-place density described as “loose” to “very loose”, one dimensional compression or collapse potential test shall be performed to evaluate the need for over-excavation. In the situation of clayey subgrade soil classified as “soft” to “very soft”, compression or consolidation test shall be performed for the same purpose.

Table 24. Sample Frequency for Pavement Design		
Test	Number of Samples for Design	
	Preliminary	Final
$Sieve$ & PI	2 per mile (min. of 3)	4 per mile (min. of 3)
$R - Value$	1 per mile (min. of 3)	2 per mile (min. of 3)
pH & Min. Resistivity	--	1 per culvert location or along metal pipelines[a]
Chloride and sulfate	--	At concrete structure locations[b]
One-dimensional Swell if $PI > 15$ and $P_{200} > 20$	3 per pavement section	
In-place density (sand cone/rings)	Min. of 3 per significant borrow area[c] and per mile of roadway	
Moisture Content (oven)	Min. of 3 per significant borrow area[c] and per mile of roadway	
Proctor Test	Min. of 3 per significant borrow area[c] and Min. 1 per mile per soil type	

[a] Use for corrugated metal pipe requirements.

[b] Use for concrete and reinforcement requirements.

[c] Use to estimate shrinkage of borrow areas larger than 5,000 cubic yards and ground compaction in fill areas larger than 50,000 square feet. Borrow areas are on-site excavation areas where the material is generated for fill construction. This may be completed as part of the preliminary or final investigation.

Table 25. Example: Two-Mile Long Project with Low Plasticity Soils—Sample Frequency	
Item	**Frequency**
Borings	8
Sieve Analyses	8
PI s	8
$R - Values$	4
pH & Min. Resistivity	Same as number of CMP[a] crossings

[a] CMP = Corrugated Metal Pipe

A 3.7.2 R-Value Analysis

MCDOT uses the following procedure to evaluate the R-value of a subgrade based on tested R-values and correlated R-values. Correlated R-values are generated from the Sieve and PI test results.

A 3.7.2.1 Correlated R-Values

The $sieve$ and PI test results are used to calculate correlated $R - values$ using the following equations:

$$R_{cor} = 0.018e^{SPF/0.235} + 6.0$$

$$SPF = 2.05 - 0.0033\, P_{200} - 0.017\, PI$$

$$\text{If } R_{cor} > 70, \text{set } R_{cor} = 70$$

Where,

PI = Plasticity Index

P_{200} = Percentage Passing No. 200 Sieve from the sieve analysis

SPF = $Sieve$ and PI factor

Note: This equation for correlated $R - value$ is a variation of that presented in the ADOT Pavement Design Manual[8]. The equation has been adjusted to represent soils typical to Maricopa County, whereas the ADOT equation is for soils throughout the state of Arizona.

A table of test results and corresponding $R - value$ estimates is then prepared. This table includes the average and standard deviation of the correlated $R - values$ for the project. If the standard deviation of the $R - values$ is high (i.e. greater than 10), the design engineer shall review the project and site conditions to see if the project should be divided into multiple segments to accommodate different pavement sections. If more than one segment is warranted, then a correlated $R - value$ table shall be prepared for each segment. A separate table is not necessary for pavement sections designed using the same subgrade resilient modulus.

Selection of which subgrade samples will be tested for $R - value$ is made after reviewing the $Correlated\ R - value$ table. The samples shall be selected such that $R - values$ will be measured from the full range of $Correlated\ R - values$ on the project. The number of $R - values$ tested should be about ½ the number of subgrade $sieve$ and PI results. This means that only half of the held samples in the laboratory would be used. However, a minimum of 3 measured $R - values$ is required for each project or each segment of a project.

EXCEPTION: If the average $Correlated\ R - value$ is 50 or greater and the standard deviation is less than 10, it is not necessary to run any $R - values$. The mean $R - value$ can be calculated from the correlated values.

The pavement designer may elect to select samples for $R - value$ testing based on visual descriptions of the soils prior to $Sieve$ and PI testing in order to save time. This will be considered acceptable if the engineer's judgment and visual classification skills are sufficient to accomplish the intent of the selection process. If the criteria of the selection process are not met, additional samples shall be tested to establish a reasonably accurate understanding of the subgrade modulus.

A 3.7.2.2 Calculation of Design R-Value

After the selected $R - value$ tests are completed, the results shall be added to the $Correlated\ R - value$ table for analysis. Average and standard deviation values for measured $R - values$ shall be made separate from those for the $Correlated\ R - values$.

The pavement designer reviews the average and standard deviation values of both $Measured$ and $Correlated\ R - values$ to make the final decision about recommending different segments. Again, separate summary tables are to be prepared for each segment of work (different subgrade) if different subgrade resilient modulus (M_R) values are used.

A 3.7.2.2.1 Adjustment for Highly Variable Soil Conditions

If the standard deviation of either correlated or measured $R - value$ is greater than 10, an adjusted average value shall be calculated to reduce the value by the amount in excess of 10. No adjustment should be made if the standard deviation is less than 10. For Example:

$$Average\ R - value \ = \ 27$$

$$Standard\ Deviation \ = \ 13$$

$$Adjusted\ Average\ R - value \ = \ 27 - (13 - 10) \ = \ 24$$

A 3.7.2.2.2 Calculate Mean R-Value

A mean R-value is then calculated using the following equation:

$$R_{mean} = \frac{2N_tR_tSD_c^2 + N_cR_cSD_t^2}{2N_tSD_c^2 + N_cSD_t^2}$$

Where,

N_t = number of measured $R - values$

N_c = number of correlated $R - values$

R_t = adjusted average of the measured $R - values$

R_c = adjusted average of the correlated $R - values$

SD_t = standard deviation of the measured $R - values$

SD_c = standard deviation of the correlated $R - values$

For MCDOT designs, the maximum value of calculated mean R-value should be limited to 45. The mean R-value is then input into the program and the program will compute the corresponding subgrade soil resilient modulus. If the calculated subgrade soil resilient modulus is greater than 26,000 psi, the value used for design purposes should be 26,000 psi.

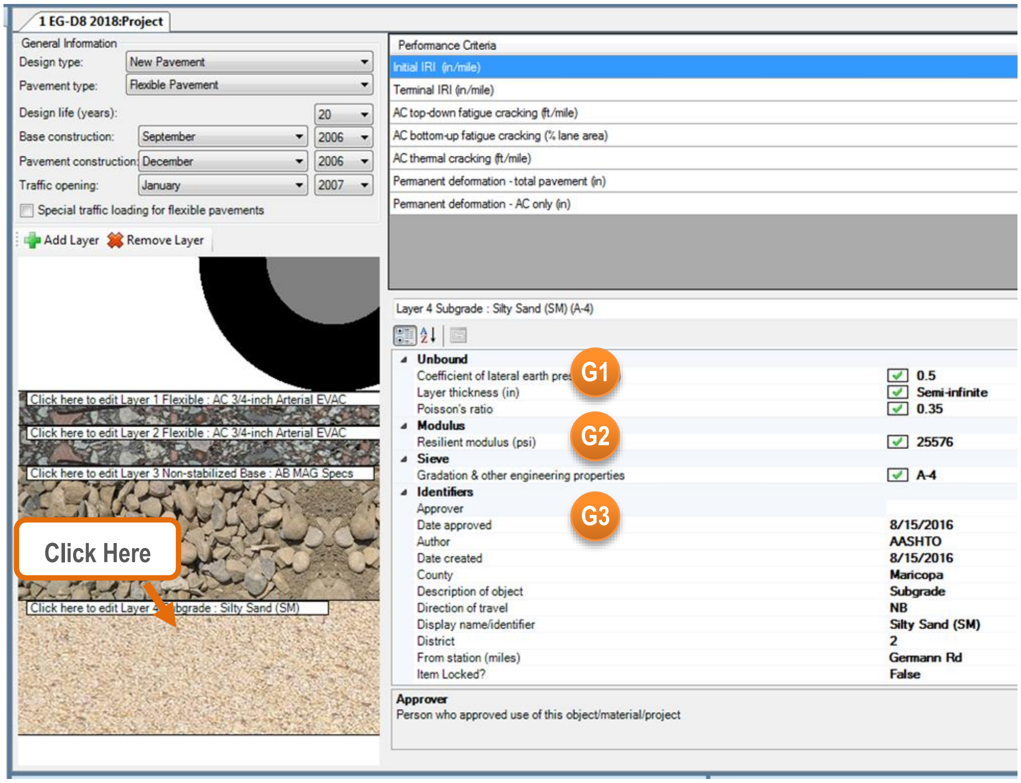


Figure 26. Material Data (Subgrade) Input Screen of Pavement ME Design Software

A.3.7.3 Unbound—Subgrade

At the time of the design phase of a project, the site specific geotechnical report will be available for the designer. This report will provide most of site specific data for the subgrade.

County designs require at least the top 6 inches of subgrade be compacted and prepared before constructing the next structural layer. To model this in the Pavement ME Design program, introduce a finite subgrade layer with a specified thickness (6-inch minimum) and click to select that the layer is compacted. The lowest layer will be the semi-infinite subgrade, with the same properties of the compacted layer, except that the layer is not compacted.

As mentioned above, at least 6 inches of compacted subgrade should be included in the pavement structure. The values for compacted subgrade parameters are input in Area **G1** of the material data (subgrade) screen (**Figure 26**). If no specific data are available, the typical values of compacted subgrade parameters given in **Table 26** should be used.

Table 26. Typical Compacted Subgrade Parameters

Parameter	Units	Value
Coefficient of Lateral Earth Pressure (k_o)	--	0.5
Layer Thickness	inches	6 (minimum)
Poisson's Ratio	--	0.35

A.3.7.3.1 Modulus—Subgrade

The resilient modulus of the unbound subgrade layer is entered in Area **G2** of the material data (subgrade) screen (**Figure 26**). The data input is exactly same as for the unbound AB layer. The current ME Design program does not provide a Level 1 input option for resilient modulus of subgrade materials. Only available input levels are Levels 2 and 3 as shown in **Table 27**.

Table 27. Resilient Modulus of Subgrade

Hierarchical Level	Data Type	Remarks
Level 1	Program does not support this yet.	
Level 2	Direct input of resilient modulus	From an actual test.
	Or, input one of following: 1. California Bearing Ratio (CBR) (%) 2. R-Value 3. Layer Coefficient-a_i 4. Dynamic Cone Penetrometer (DCP) Penetration (in/blow) 5. Based on Plasticity Index (PI) and Gradation	Three analysis types are available to select, as follows: (c) Modify input values by temperature/moisture; or (d) Monthly representative values; or (c) Annual representative values.
Level 3	Direct input of resilient modulus. Can be obtained from a correlation.	Two analysis types are available to select, as follows: (a) Modify input values by temperature/moisture; or (b) Annual representative values.

For MCDOT designs, the preferred method is to use input Level 2, enter design R-Value (Section A3.7.2.2), and select Modify input values by temperature/moisture. Refer to Section 3.7.2 for R-value analysis for a project. If no R-value data is available, select one of the other options.

A.3.7.3.2 Sieve—Subgrade

Enter gradation and other engineering properties in Area **G3** of the material data (subgrade) screen (**Figure 26**). Site specific data should be available from the geotechnical report prepared for the site. Typically, the saturated hydraulic conductivity and SWCC data are not readily available for a soil. Therefore, allow the program to calculate the values based on other properties entered.

As mentioned in a previous section, SWCC is the relationship between the degree of saturation, S, and the matric suction, h, of the soil. When the soil is partially saturated, there is a corresponding negative pore water pressure (in other words matric suction) in the soil depending on the type of soil as shown in **Figure 25**.

A.3.8 Material Characterization—Treated Subgrade

MCDOT uses lime-stabilized and cement stabilized subgrades when problematic soils are encountered. However, the Pavement ME Design has no specific layer listed to be used as a treated subgrade at the time of this document. Therefore, compacted subgrade layer can be introduced above the native subgrade to model a treated subgrade in Level 2 with an appropriate layer coefficient for resilient modulus calculation (**Figure 27**).

MCDOT has adopted a layer coefficient, a_i, of 0.16 for both lime-stabilized and cement-stabilized bases. Refer to Chapter 10 of MCDOT RDM.

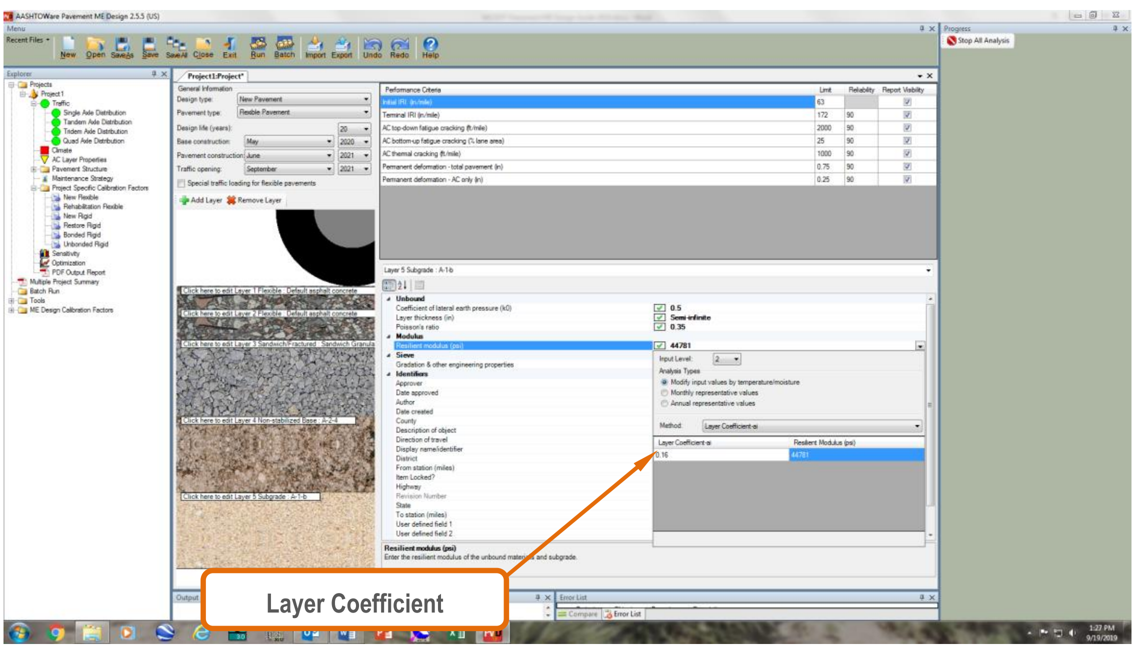


Figure 27. Material Data (Subgrade) Input Screen of Pavement ME Design Software

A.4 Running Pavement ME Design

A.4.1 Local Calibration Factors

Local calibration performed by MCDOT resulted in adjusting three calibration factors as shown on the last column in **Table 28.** All other calibration factors remain the same.

Table 28. Local Calibration Factors for MCDOT

Distress Type	Parameter	National Factor		MCDOT Factor
		v 2.3.0	v 2.5.5	
AC Cracking-Bottom Up	**C2** < 5 in.	1.0	2.1585	**2.0**
AC Rutting (all layers)	**BR1**	1.0	0.40	**0.69**
IRI Flexible	**C4**	0.015	0.015	**0.033**

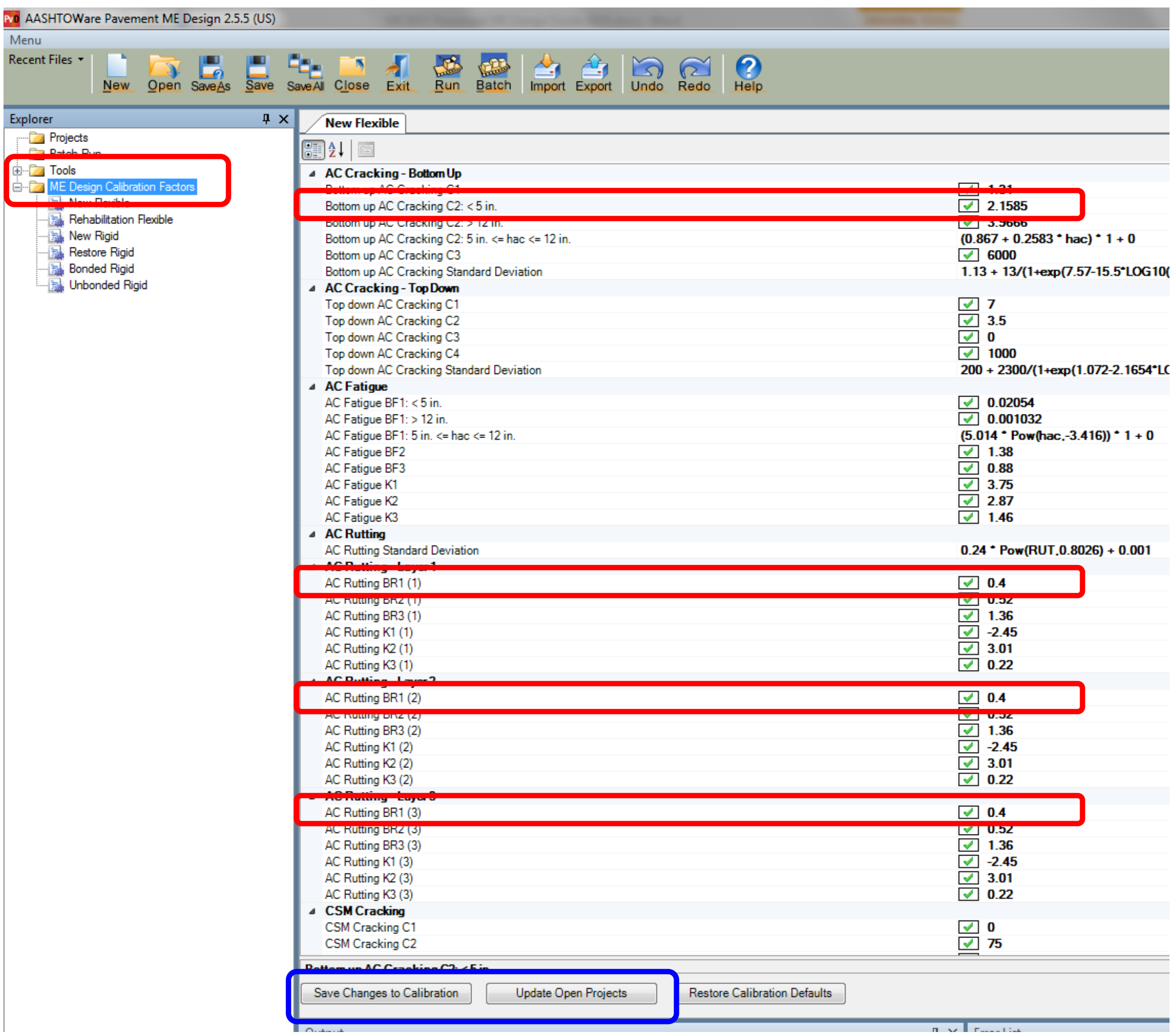


Figure 28. ME Design Calibration Factors

To change the calibration factors, refer to **Figure 28** and follow the steps shown below:

1. Open the program and expand **ME Design Calibration Factors** on the file tree. Area **H** on the data input screen (**Figure 8**).
2. Double click on **New Flexible**
3. To change AC Cracking-Bottom Up **C2 < 5 in.**, find the line containing Bottom Up AC Cracking < 5 in., click on the current value 2.1585, and change the value to **2.0**.
4. To change AC Rutting **BR1**, scroll down the page find AC Rutting section, and change the AC Rutting **BR1** value of all the layers, i.e. BR1(1), BR1(2), and BR1(3), from 0.4 to **0.69**.
5. To change IRI Flexible **C4**, scroll further down the page, find IRI section, and change the value of IRI Flexible **C4** from 0.015 to **0.033**.
6. Once all the calibration factors are adjusted, click on the two tabs, **Save Changes to Calibration** and **Update Open Projects**. (see the blue box in **Figure 28**).
7. Once new values are stored, the program will continue to use them until they are changed manually.

A.4.2 Running the Program

Once the data input is complete, the three circles in front of Traffic, Climate, and AC Layer Properties in the file tree in Area **H** of the data input screen in **Figure 8** turn GREEN indicating that the program is ready to be executed. **Figure 29** shows an enlarged view. If the circles are RED, no data has been entered yet. Once the data entering begins, the circles turn YELLOW indicating that the data entering is in progress, but not complete.

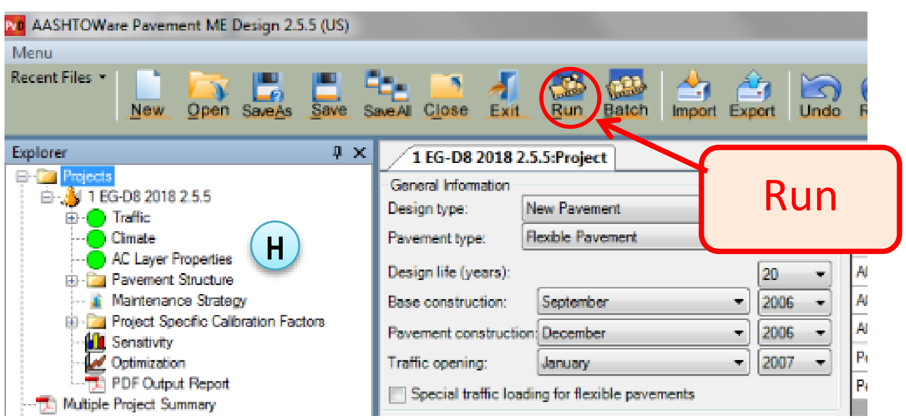


Figure 29. Close up of Area H

The program can be executed by clicking Run button on the menu (**Figure 29**). The progress of analysis is shown in Area **I** of the screen shown in **Figure 30**.

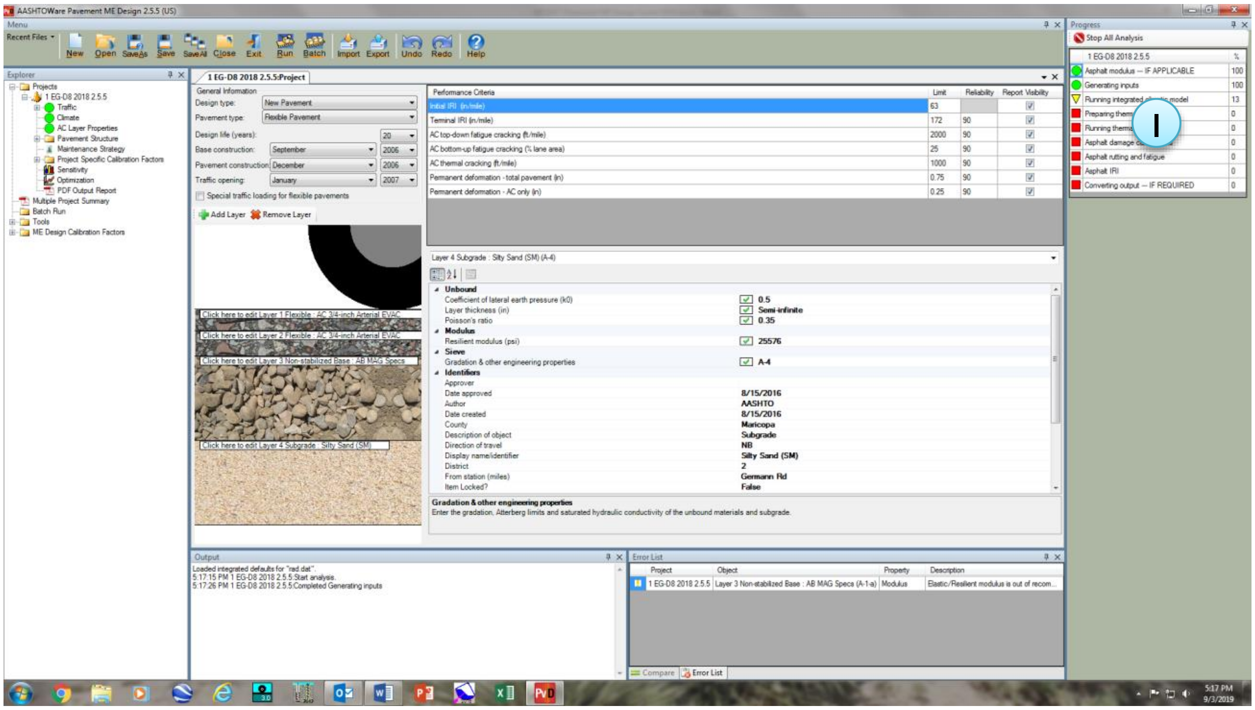


Figure 30. Progress of Analysis in Pavement ME Design Software

A.4.3 Program Output

The program goes through the steps shown in **Figure 31** and generates an output report that includes the design inputs, design structure, and design outputs on the first page (**Figure 32**). The design output shows the distress prediction summary and tells the designer if the design performance criteria are met for each distress type. **Table 3** gives the performance criteria for each distress types.

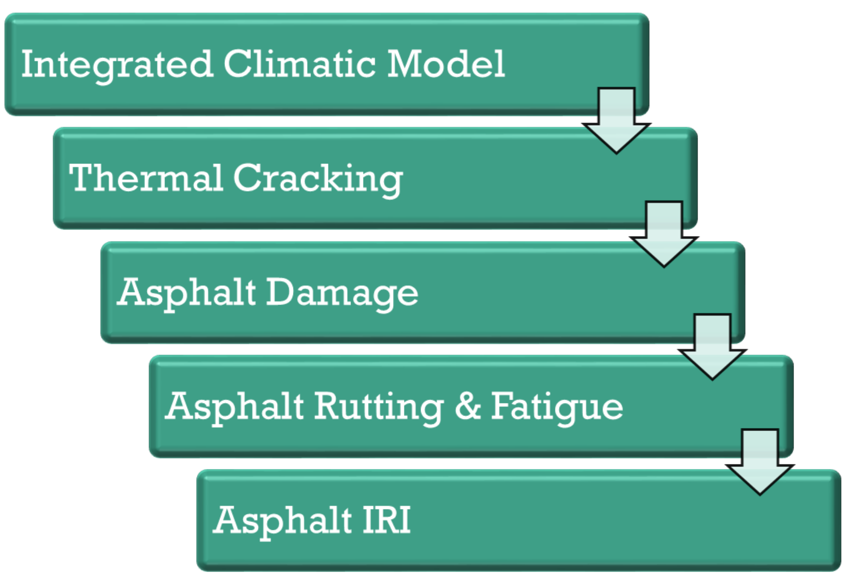


Figure 31. Steps of Analysis in Pavement ME Design Software

The rest of the output report gives distress charts, traffic inputs, climate inputs, hot-mix asphalt (HMA) design properties, thermal cracking input, HMA layer data charts, analysis output charts, layer information, and calibration coefficients. A few examples of output report pages are shown in **Figures 32** through **34.**

1 EG-D8 2018

File Name: C:\Users\yasanayakeg\Desktop\1 EG-D8 2018.dgpx

Design Inputs

Design Life: 20 years
Design Type: FLEXIBLE

Base construction: September, 2006
Pavement construction: December, 2006
Traffic opening: January, 2007

Climate Data Sources (Lat/Lon): 33.5, -111.875

Design Structure

Layer type	Material Type	Thickness (in)
Flexible	AC 3/4-inch Arterial EVAC	2.5
Flexible	AC 3/4-inch Arterial EVAC	3.0
NonStabilized	AB MAG Specs	10.0
Subgrade	Silty Sand (SM)	Semi-infinite

Volumetric at Construction:	
Effective binder content (%)	14.3
Air voids (%)	5.8

Traffic

Age (year)	Heavy Trucks (cumulative)
2007 (initial)	1,626
2017 (10 years)	3,623,460
2027 (20 years)	10,489,300

Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in/mile)	172.00	151.14	90.00	97.41	Pass
Permanent deformation - total pavement (in)	0.75	0.36	90.00	100.00	Pass
AC bottom-up fatigue cracking (% lane area)	25.00	1.45	90.00	100.00	Pass
AC thermal cracking (ft/mile)	1000.00	3197.38	90.00	9.46	Fail
AC top-down fatigue cracking (ft/mile)	2000.00	1328.64	90.00	97.38	Pass
Permanent deformation - AC only (in)	0.25	0.16	90.00	99.98	Pass

Figure 32. Output Report—The First Page

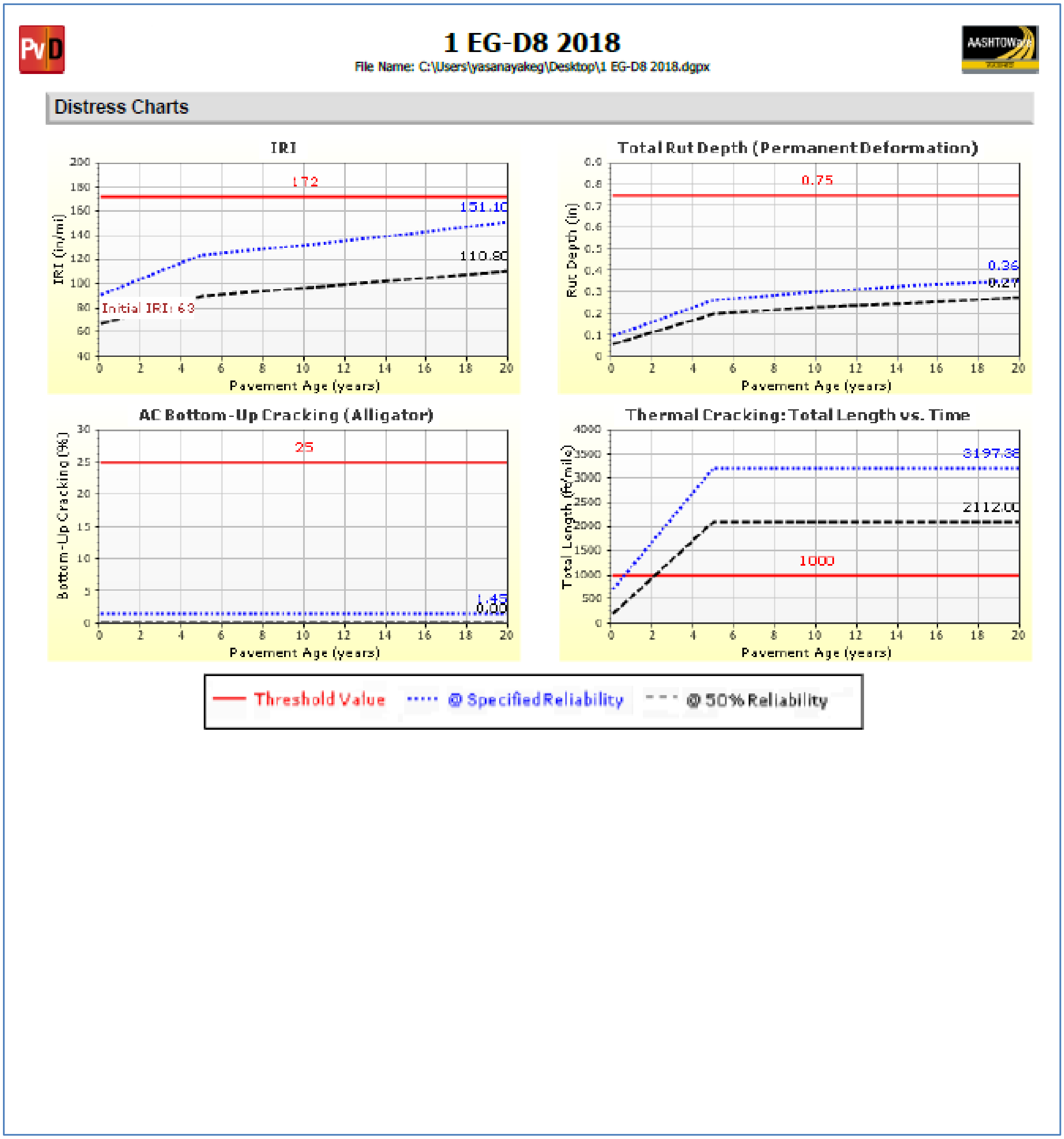
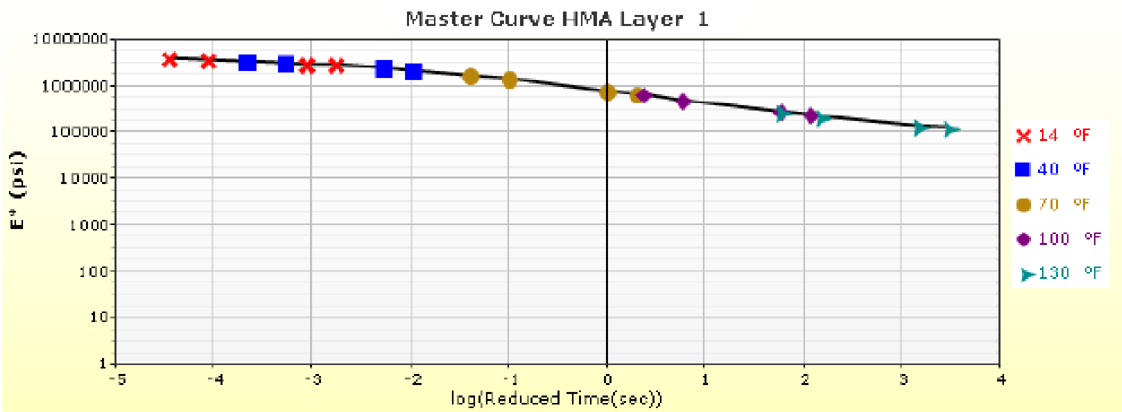


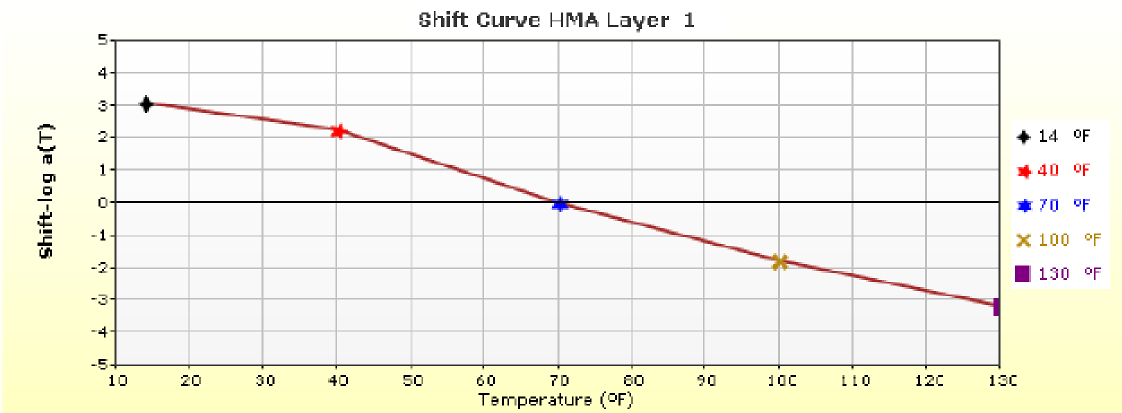
Figure 33. Output Report—Distress Charts

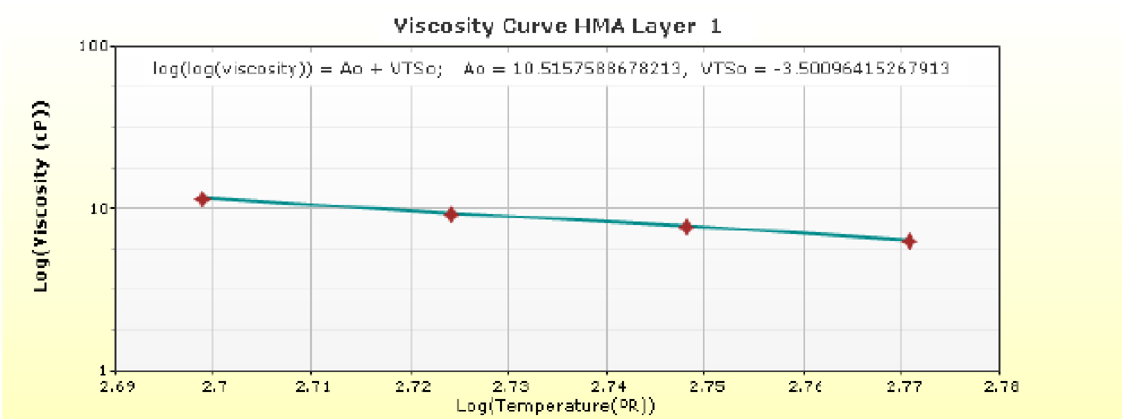
1 EG-D8 2018

File Name: C:\Users\yasanayakeg\Desktop\1 EG-D8 2018.dgpx

HMA Layer 1: Layer 1 Flexible : AC 3/4-inch Arterial EVAC







Reported with version: 2.5.5+7117.27682 on: 7/31/2019 2:57 PM

Created with version: N/A on: 4/18/2016 12:00 AM by: Gant Y.

Approved with version: 2.5.5+7117.27682 on: 4/18/2016 12:00 AM by:

Page 10 of 21

Figure 34. Output Report— HMA Layer Data Charts

A.4.4 Interpretation of Results

The first page of the output report gives the distress prediction summary (**Figure 32**). If the design is satisfactory, the last column of the distress prediction summary (Distress Satisfied?) will show **Pass** for all six distress categories. If there are distresses showing **Fail**, the pavement structure is under designed and the program should be rerun by increasing the layer thicknesses or changing material properties if appropriate.

It should be noted that it is possible to have an overdesign of structure, if the program is run with layer thicknesses larger than necessary. In this case, design optimization is necessary. Currently, optimizing flexible pavement designs require manual iterations. NOTE: Pavement ME Design provides design optimization as part of the run only for Jointed Plain Concrete Pavement (JPCP) analyses.

A.4.5 Running Errors and Help

If program encounters errors while running, click the Error List tab at the bottom of the screen (**Figure 35**) to see the error list, correct the problem, and rerun the program.

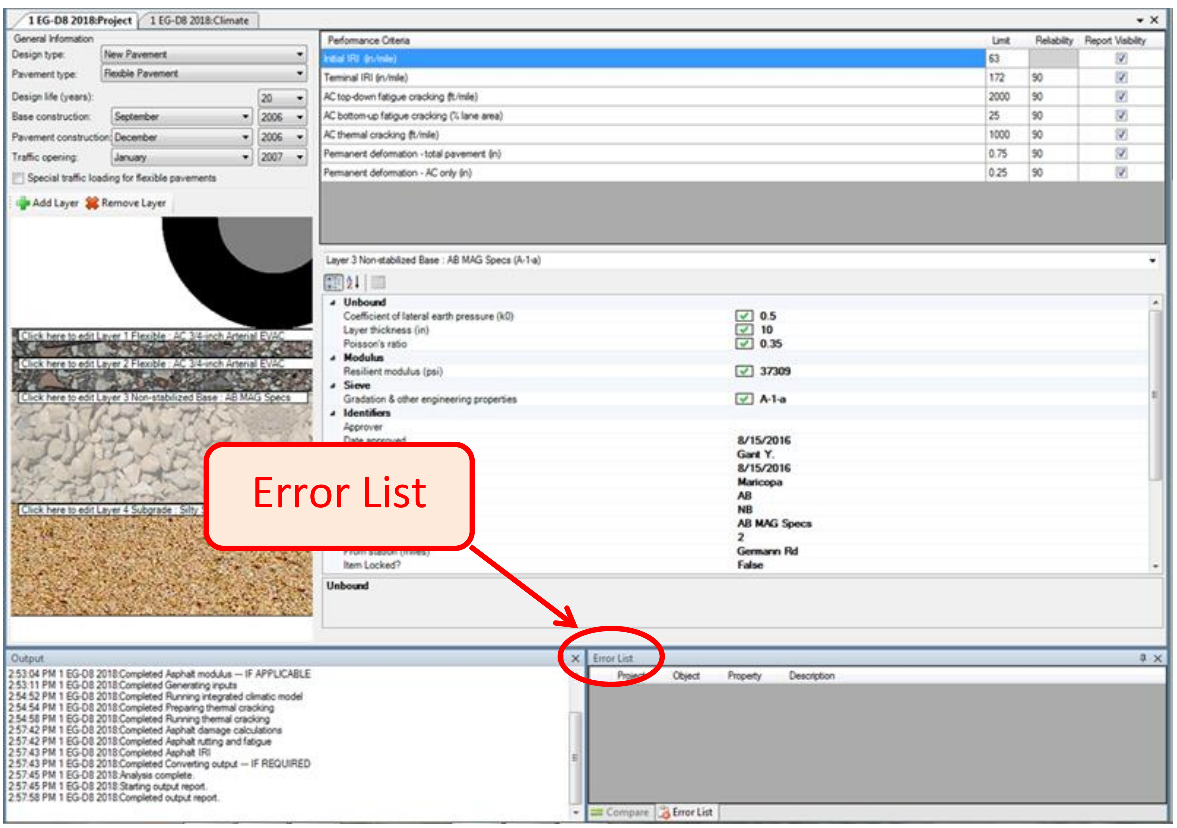


Figure 35. Running Errors

Information about specific program topics can be obtained by clicking Help (**Figure 36**) and navigating to the desired topic. Help topics shown in **Figure 37** are currently available.

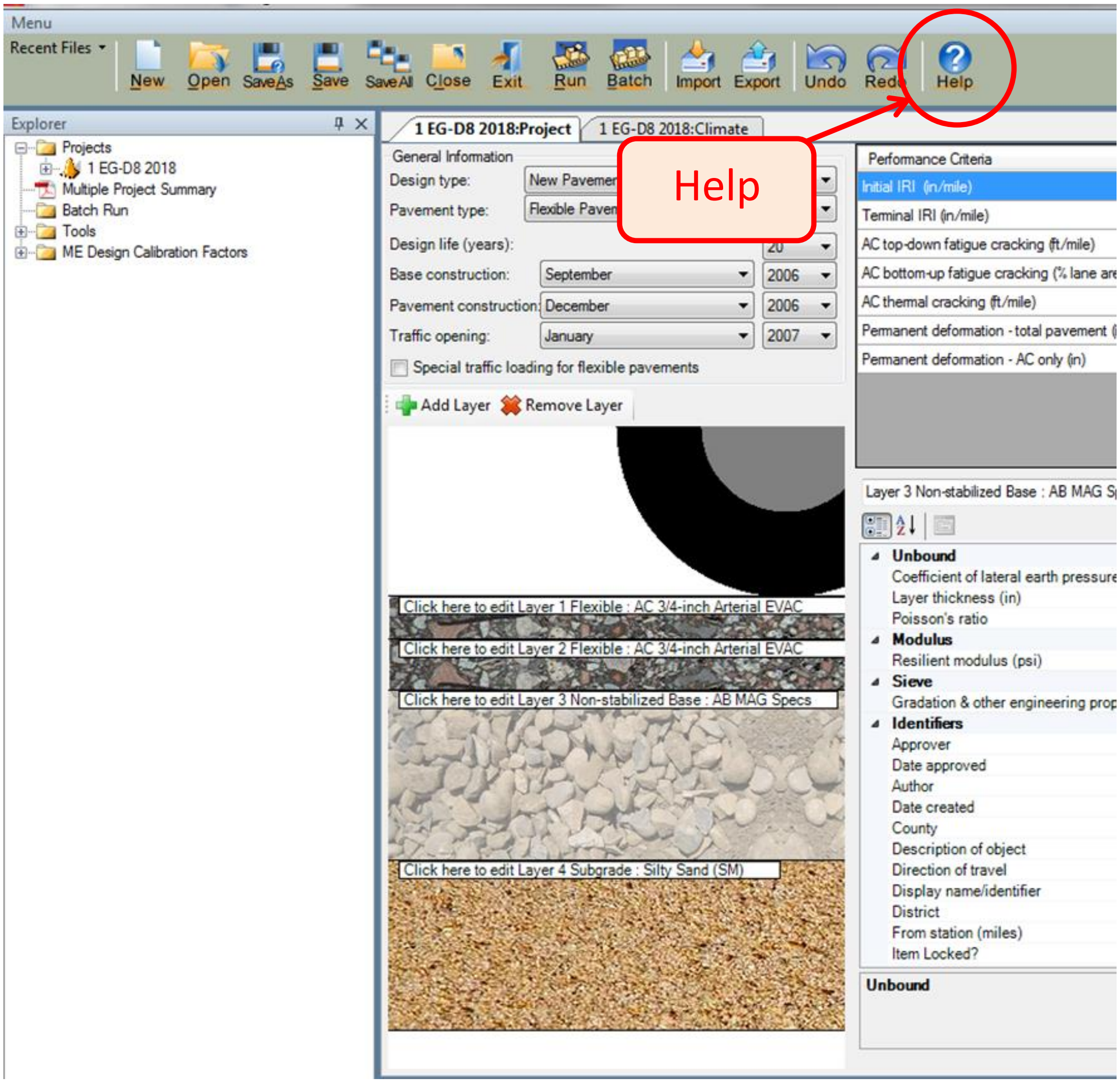


Figure 36. Menu of Pavement ME Design Software—Help Button

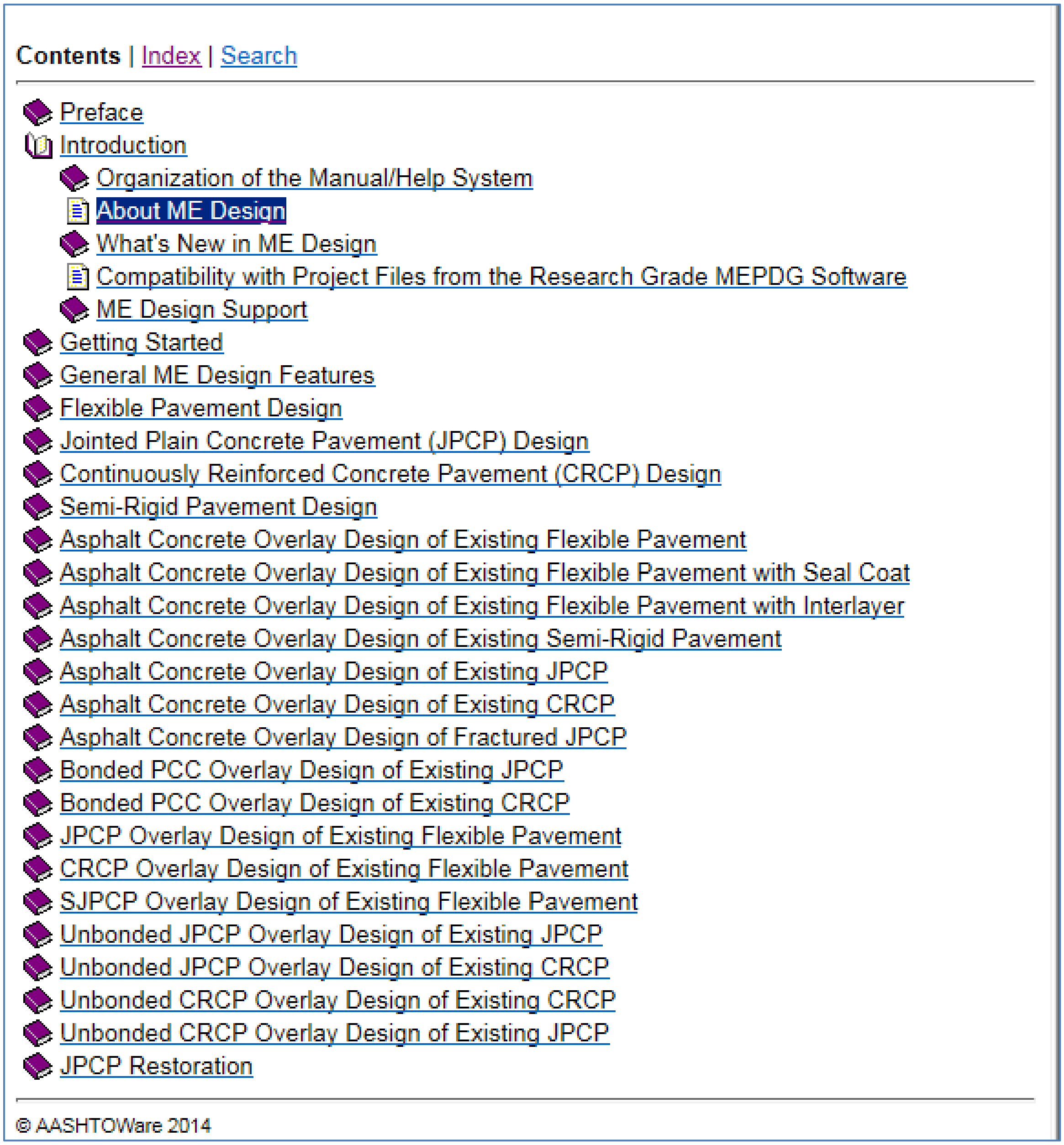


Figure 37. Contents of ME Pavement Design HELP

A 5. References

1. MCDOT Roadway Design Manual 2019.

2. AASHTO Guide for the Local Calibration of the Mechanistic-Empirical Pavement Design Guide, November 2010.

3. Implementation Process of Pavement ME Design in Maricopa County, 13th Arizona Pavement/Materials Conference, November 2016.

4. AASHTOWare Pavement ME (Mechanistic Empirical) Pavement Design Software Program.

5. Maricopa Association of Governments (MAG) Regional Travel Demand Forecasting Model.

6. Maricopa County 2019 Supplement to the MAG (Standard details are included).

7. Uniform Standard Specifications and Details for Public Works Construction by Maricopa Association of Governments.

8. ADOT Pavement Design Manual (September 2017).

■■■